

(NASA-CR-151954) STATIC, NOISE, AND
TRANSITION TESTS OF A
COMBINED-SURFACE-BLOWING V/STOL
LIFT/PROPULSION SYSTEM (Boeing Vertol Co.,
Philadelphia, Pa.) 254 F HC A12/MF A01

N77-26139

Unclas
G3/07 36657

NASA CR-151954

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By

Allen H. Schoen, Charles E. Kolesar,
and Edward G. Schaeffer

April 1977

Prepared under Contract No. NAS2-9169

By

Boeing Vertol Company
Philadelphia, Pennsylvania

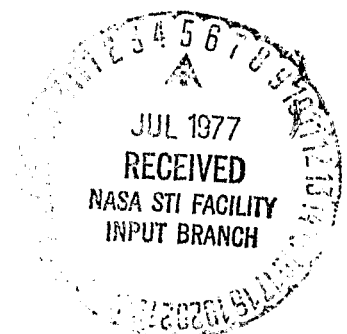
for

National Aeronautics and Space Administration

Ames Research Center

and

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Prepared under Contract No. NAS2-9169 by

BOEING VERTOL COMPANY
A Division of The Boeing Company
P. O. Box 16858
Philadelphia, Pennsylvania 19142

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Ames Research Center

and

NAVAL AIR SYSTEMS COMMAND

FOREWORD

This program was conducted under Contract NAS2-9169 from NASA-Ames Research Center, sponsored jointly by NASA and the Naval Air Systems Command. The program technical monitors were David G. Koenig of Ames Research Center and Lynn Trobaugh of David Taylor Naval Ship Research and Development Center.

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NOMENCLATURE

A_{eff}	Effective nozzle-exit area ($\text{m}^2, \text{in.}^2$)
AF	Total axial force on model (n, lb)
AR	Wing aspect ratio
c	Wing chord (m, ft)
C_j	Thrust coefficient, $\frac{F_{\text{gross}}}{q S_{\text{REF}}}$
C_L	Lift coefficient, $\frac{L}{q S_{\text{REF}}}$
$C_{L\text{CIRC}}$	Circulatory-lift coefficient, $C_L - C_j \sin(\alpha + \delta_f)$
ΔC_L	Induced lift, $C_L - C_{L,O} - C_j \sin(\alpha + \delta_f)$
$C_{L,O}$	Power-off lift coefficient (evaluated at $F_{\text{net}} = 0$)
C_m	Pitching-moment coefficient, $\frac{M_c/4}{q S_{\text{REF}} c}$
C_x	Chord force coefficient, $\frac{X}{q S_{\text{REF}}} - \sqrt{2 \frac{A_{\text{eff}}}{S_{\text{REF}}}} C_j$
$DELJ$	Thrust-vector angle = $\tan^{-1} \frac{NF}{AF}$
e	Span-loading (induced drag) efficiency
F_{net}	Net thrust (n, lb)
F_{gross}	Gross thrust (n, lb)
F_{REF}	Reference thrust, evaluated as model resultant static force with $\delta_f = 0^\circ$ (n, lb)
HP	Horsepower required for steady flight
Ind Drag	Induced-drag parameter = $\frac{C_L^2}{\pi AR + 2 C_j}$
L	Lift (n, lb)

M_j	Jet Mach number
$M_{c/4}$	Pitching moment about wing quarter chord (n-m, ft-lb)
NF	Total normal force on model (n, lb)
PL	Local exit ambient static pressure (n/m^2 , psf)
Pt	Air-pod total pressure (n/m^2 , psf)
PNLT	Tone-corrected perceived noise level (db)
q	Tunnel dynamic pressure (n/m^2 , psf)
q_t	Dynamic pressure at position of horizontal tail (n/m^2 , psf)
RF	Model resultant force (n, lb)
R/C1	Rate of climb for representative airplane with wing loading of 100 psf (meters per minute, feet per minute)
S_{REF}	Reference semispan wing area (m^2 , ft^2)
TRFLAP	Thrust recovery of flap system, RF/F_{REF}
V	Airspeed (m/sec, knots)
VK1	Flight-path speed (m/sec, knots)
X	Chord force, positive forward (n, lb)
α	Wing angle of attack (deg)
δ_f	Flap deflection (deg)
ϵ	Downwash angle at tail (deg)
θ_W	Wing attitude reference to horizon (deg)

STATIC, NOISE, AND TRANSITION TEST OF A COMBINED-SURFACE-BLOWING V/STOL LIFT/PROPULSION SYSTEM

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1.0 SUMMARY

A test has been conducted on a half model of a V/STOL airplane using a Combined-Surface Blowing (CSB) lift/propulsion system. The CSB system is a type of externally blown jet flap in which the jet exhaust from wing-mounted cruise fans is directed over both upper and lower surfaces of a flapped wing. The flap system serves as a thrust deflector. Previous testing on this concept had shown that CSB offers a unique combination of VTOL performance due to efficient thrust-vectoring and good STOL performance due to high levels of circulatory lift.

The test discussed in this report provides additional confirmation of these capabilities and provides a data base of noise measurements on the CSB system. During a four-week test program the following was accomplished: static-performance studies were made through a series of methodical variations of flap configuration; the transition-flight region was explored with particular emphasis on steep-descent capability; and the acoustical characteristics were measured for combined blowing and blowing upper or lower surface only.

Approximately 90-percent thrust recovery with 87 degrees of thrust vectoring was achieved under static conditions using 89 degrees of trailing-edge flap deflection. The approximately 10-percent loss appears to be associated primarily with pressure losses due to the flap brackets or slot entries. Further refinement in these areas may provide additional performance.

The jet-induced lift was shown to be 55 percent of the theoretical value for a fullspan jet-flapped wing, even though only 27½ percent of the wingspan was immersed in the jet. Steady rate-of-descent capability in excess of 1,000 feet per minute is predicted for an airplane using the CSB system. This is in excess of previous test results and is excellent performance in view of the exploratory nature of the test.

Both combined blowing and lower-surface blowing have higher noise levels than upper-surface blowing, although this difference diminishes with increasing thrust. There is little noise difference between combined and lower-surface blowing at low thrust levels. However, as thrust increases the lower-surface noise increases much more rapidly. This indicates the possibility of significant aerodynamic-noise cancelling when blowing over both surfaces at high velocities.

2.0 INTRODUCTION

2.1 Background

One of the primary design problems of V/STOL aircraft with nontilting fans is the development of an efficient thrust-vectoring system. A number of different approaches for directing the thrust from cruise mode (longitudinal) to hover mode (vertical) have been proposed, ranging from vectoring nozzles and cascades to tail-sitter aircraft configurations. In general, while these concepts satisfy the V part of V/STOL, they pay little attention to the S requirement; and experience has shown that efficient utilization of V/STOL aircraft will involve both VTOL- and STOL-mode operations.

Substantial research and development have been conducted since the 1960's on advanced STOL lift/propulsion systems, including the Upper-Surface Blowing (USB) and Externally Blown Flap (EBF) jet-flap concepts. These concepts are attractive for STOL application because they use adaptations of conventional high-lift flap systems for powered lift, and since the wing-flap system serves as the thrust deflector, significant additional circulatory lift (supercirculation) is developed. Although these concepts satisfy the requirement for efficient thrust vectoring during STOL-mode operations, they have not been recommended for VTOL configurations because of their unacceptably high thrust-turning losses at the high deflection angles required for VTOL flight.

One specialized jet-flap concept studied during early NASA testing (ref. 1) was found to have unusually good static-thrust-vectoring efficiency in addition to good STOL performance; thus, it suggested the development of an effective V/STOL configuration. The Combined-Surface Blowing (CSB) concept which showed these characteristics consists of a wing-mounted cruise fan whose exhaust is directed in combination over both upper and lower surfaces of the flapped wing, to be deflected by the flap system (Figure 2.1-1). Although research on CSB was discontinued due to emphasis on purely STOL design, recent interest in VTOL has led to a re-examination of this attractive V/STOL concept.

2.2 Objectives

The objectives of the current investigation were to:

- a. Reevaluate the static-turning performance of a CSB lift/propulsion system for three different triple-slotted flaps and for a nozzle with a different airflow split (top to bottom) than was used during the earlier NASA research (ref. 1).
- b. Provide a base of noise data for comparing the acoustical characteristics of a Combined-Surface Blowing system with other types of V/STOL systems.
- c. Provide a broad base of transition flight data with emphasis on examination of aircraft descent capability.

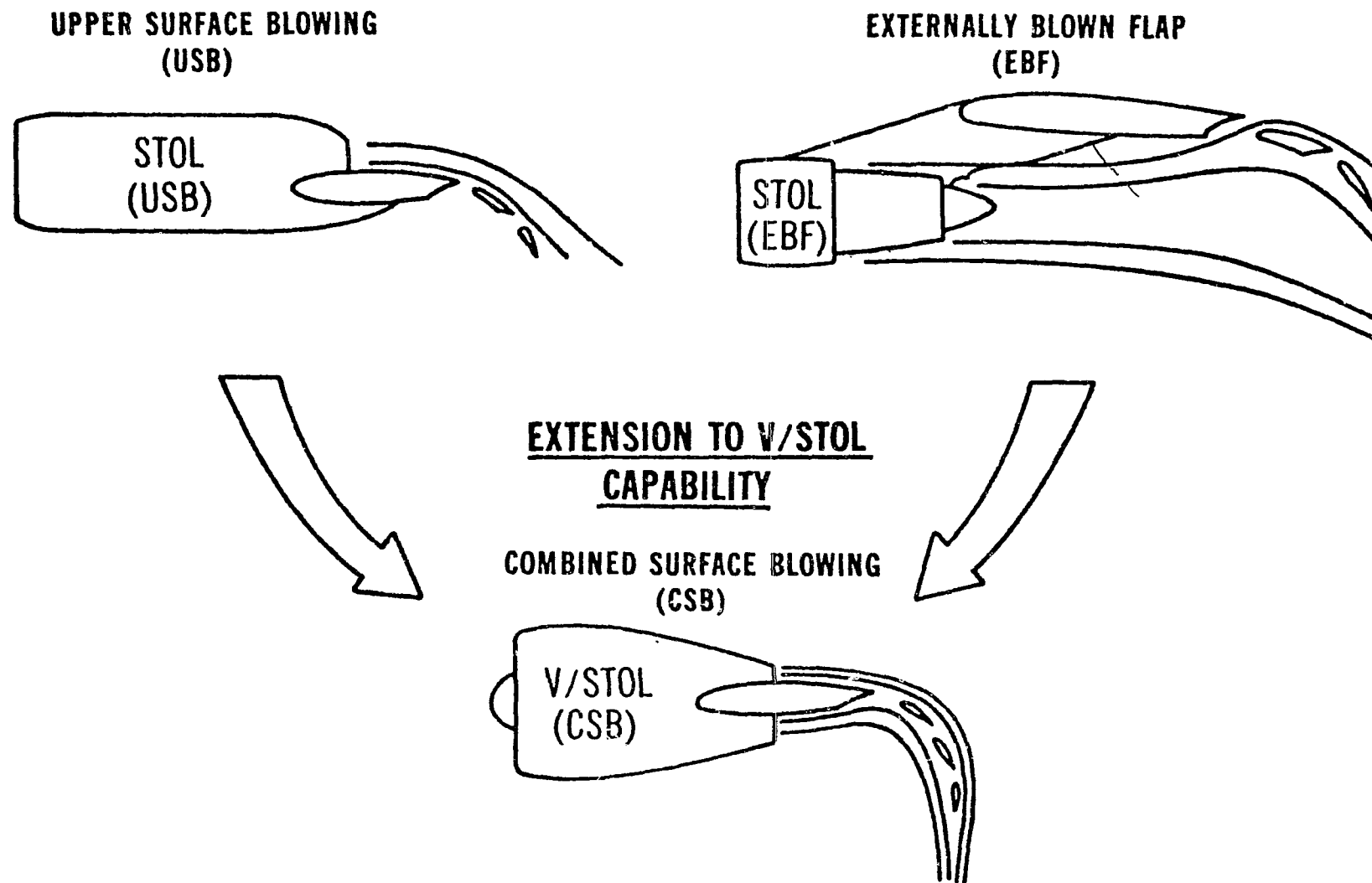


Figure 2.1-1. Combined-Surface Blowing: A Lift/Propulsion Concept With STOL and VTOL Capability

2.3 Scope

A four-week test was conducted in the Boeing V/STOL wind tunnel on a half model, consisting of a semispan wing with air pod/nozzle, triple-slotted trailing-edge flaps, and half body.

The model was tested with two different wing configurations. These are shown in Figure 2.3-1 in the extended configuration, and in Figure 2.3-2 in the retracted configuration. The geometry of the wing configurations is detailed in Figure 2.3-3 and Table 2-1. The retracted configuration involved decreasing the wingspan of the extended wing approximately one-third by shortening the model post-mount height. This retraction eliminated the inboard segment of the three spanwise-segmented trailing-edge flaps. Figure 2.3-4 shows the assembly of the wing, flaps, air pod, and nacelle.

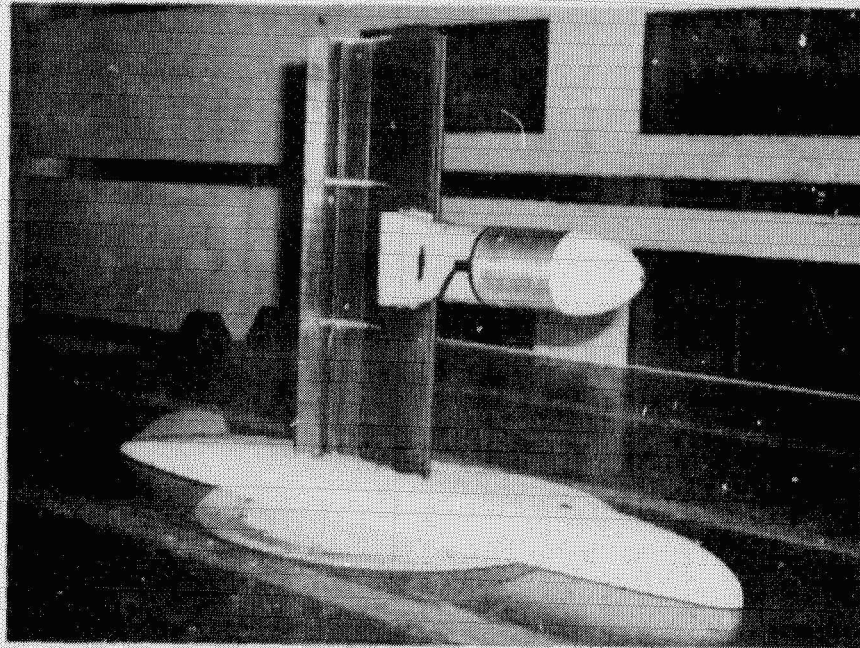
TABLE 2-1. WING GEOMETRY

Chord	1.0715 ft
Extended span (2 x semispan, excluding round tip)	8.792 ft
Extended area (2 x reference area)	9.421 ft ²
Extended aspect ratio	8.205
Retracted span (2 x semispan, excluding round tip)	6.146 ft
Retracted area (2 x reference area)	6.585 ft ²
Retracted aspect ratio	5.736
Basic wing section	63 ₃ 418
Slats	17.3% basic wing chord
Triple-slotted flaps	41% of basic wing chord (when retracted)
	Approximately 9.5% chord Fowler action at 90 degrees deflection

The test was divided into two weeks of static and noise phase testing, conducted with the extended-wing configuration, and two weeks of transition phase testing with both the extended and retracted wings. Figures 2.3-5 and 2.3-6 are photographs of the model in the extended-wing configuration mounted on the ground board with the microphones in place for the noise measurements. In these photos, both test-section walls and ceiling have been removed for the static-phase testing.

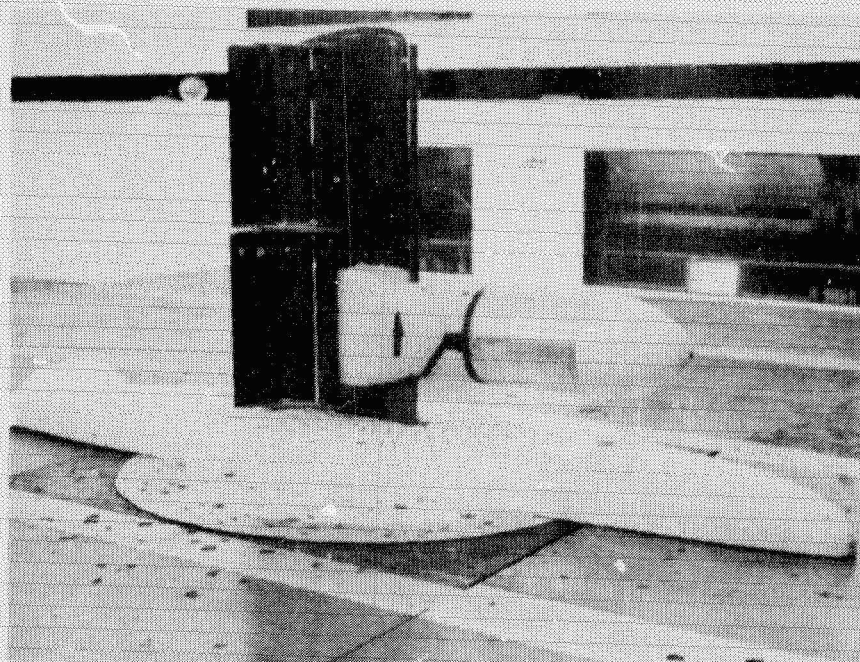
The test was exploratory — to confirm the findings from the earlier NASA research of reference 1, to examine potential problem areas in the transition flight regime (for example, wing stall in the unblown region), and to determine the validity of this concept for application to an advanced V/STOL aircraft. It was anticipated that, based on the success of the results of this test with a simplified semispan model, more detailed future testing would be required to determine the effects of parameters not fully represented in the current investigation, and to investigate problem areas associated with an integrated aircraft design.

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Figure 2.3-1. Extended-Wing Configuration



C28456

Figure 2.3-2. Retracted-Wing Configuration

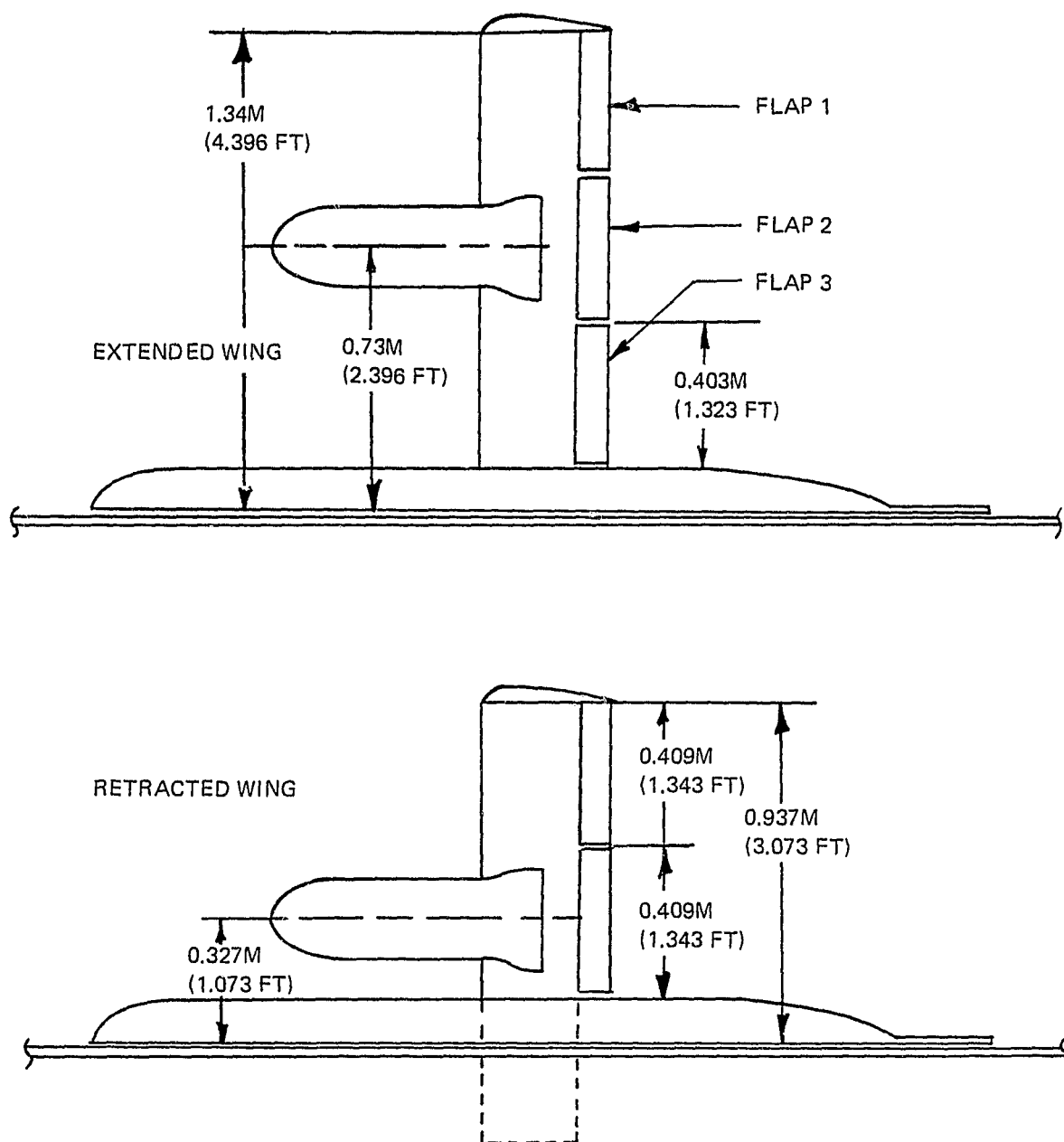


Figure 2.3-3. Wing Geometry

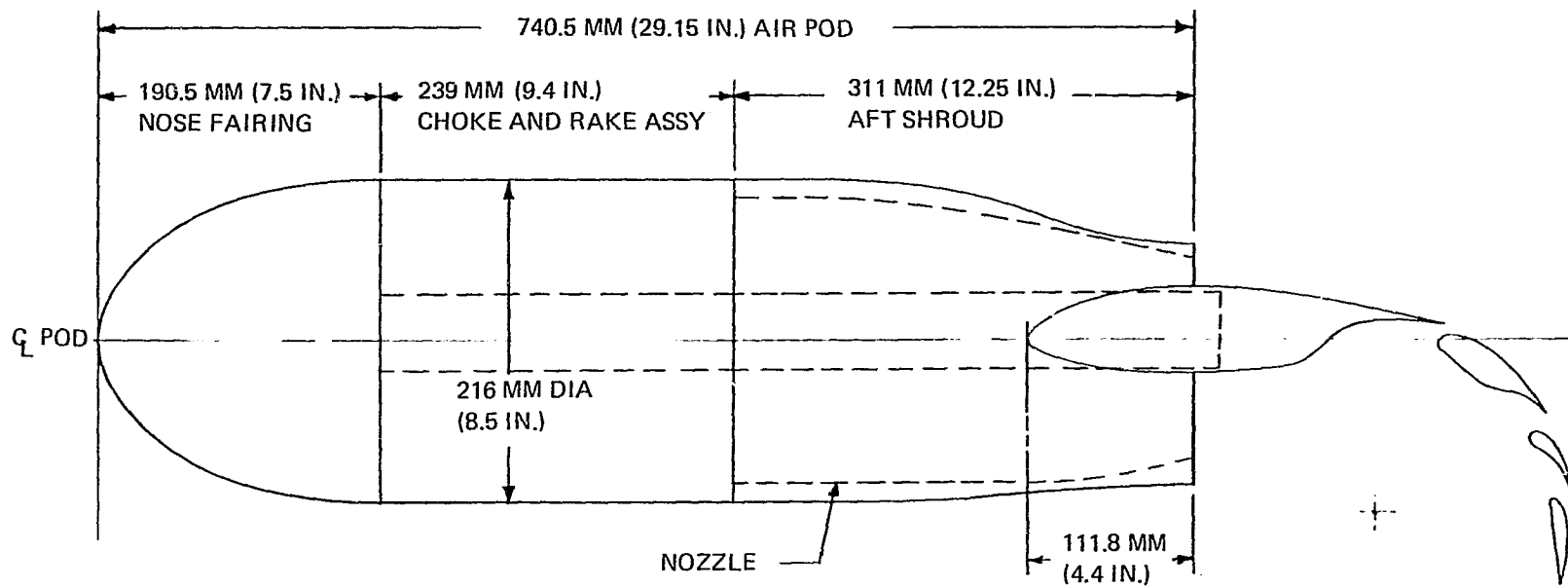
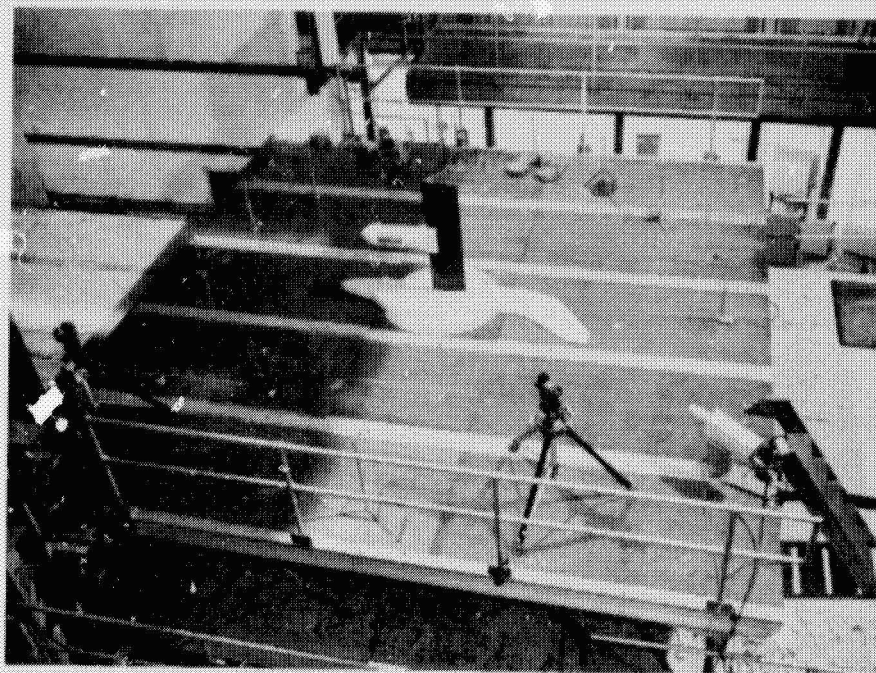
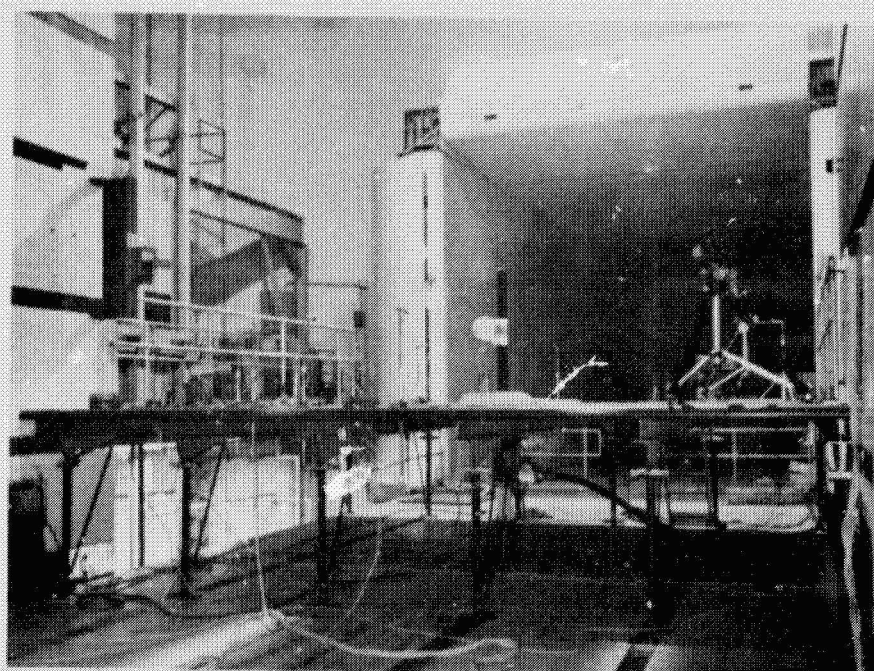


Figure 2.3-4. Cross section of Wing and Air Pod



C28366A

Figure 2.3-5. Model Installed for Static Test Phase (View Across Test Section)



C28381A

Figure 2.3-6. Model and Ground Board Installation Details (View Toward Test-Section Diffuser)

3.0 MODEL DESCRIPTION AND INSTALLATION

The general arrangement and geometry of half-span model VX-119B-2 and wind-tunnel installation details are presented in this section.

3.1 Nacelle and Nozzle Geometry

A schematic drawing showing the internal arrangement of the cylindrical nacelle, including the location of the choke plates, screen, and total-pressure rake, is presented in Figure 3.1-1. This drawing also depicts the geometric relationship between the nacelle and wing section. The air pod bisects the wing-chord plane and is mounted equidistant (spanwise) between the flap tracks.

Compressed air directed up the 0.038 by 0.076-m (1.5 by 3-inch) hollow box section of the wing was introduced into the blown pod via the centerbody feed line fastened to the front part of the box section. This air exited from the feed line through four slots at the forward end of the line and thence into the high-pressure pod plenum via a 90-degree change in flow direction. An additional 90-degree flow change was required to pass the air, in turn, through a high-pressure choke plate with 228 holes, a low-pressure choke plate also with 228 holes, a screen, past a 16-tube total-pressure rake, and then into the split nozzle. Mass flow into the pod was remotely adjusted from the test-panel-mounted control system.

Figure 3.1-2 describes the blown-nacelle nozzle used for this test. This nozzle translates from a cylindrical section at the forward face to a rectangular shape at the exit. The 0.02-square-meter (31.32-square-inch) exit, located at 32 percent of the basic wing chord, was designed to pass one part of the total nozzle mass flow over the top surface of the wing and three parts below the bottom surface. This figure also depicts the upper and lower nozzle eyebrows attached to the outer edges of the rectangular exit. These were evaluated during the static test phase and retained for the transition test phase. Each eyebrow extended over the full breadth of the exit. When this modification was installed, the added nozzle length did not include an extension on the sides of the exit.

3.2 Flap and Slat Geometry

Flaps. — The three triple-slotted-flap configurations (designated Flap A, B, and C) that were evaluated with a 90-degree deflection in the static test phase are illustrated in Figures 3.2-1 through 3.2-3. Each of these figures presents the respective flap in the best static performance configuration as determined during the test program. Noted on each figure are the selected gap and overlap for each slot.

Flap A (a conventional flap arrangement) and Flap B (the reverse arrangement) use the same three flap elements with the first and second flaps interchanged. Both flap sets, and also Flap C, nest to 40 percent of the basic wing chord when retracted, as shown in Figure 3.2-4. For Flap C, the first and second elements were redesigned to establish a second slot location about midway between the location provided by the other two flap designs. When each of the flaps was extended to the 89-degree angular setting, the extension radius as defined by the outer surface of each flap element was a constant 5.25 inches. This is shown in Figure 3.2-5.

During the static phase testing with the extended wing, each of the three flap spanwise segments was set with identical geometry. In the transition testing, the method of separately assembling the three different flap elements on its own set of flap brackets and then bolting each of the spanwise assemblies to wing/flap brackets enabled the overall spanwise flap deflections to be mixed.

The geometry used for the 75-, 60-, and 45-degree flap angles is described in Figures 3.2-6 through 3.2-8. Noted in each figure are the two sets of geometry installed for transition testing. One set was used for the blown spanwise segment and the other set, with the conventional-size gaps, was configured for the unblown spanwise segment.

Slats. — A full-span slat was installed during the transition testing to increase the stall angle of the highly flapped wing. Figure 3.2-9 and 3.2-10 depict the various slat settings evaluated plus the modification made to the basic slat contour to lessen the discontinuity at its trailing edge when installed at the steepest angle.

It can be observed from these figures that the slat was mounted on the leading edge of the basic airfoil; that is, the portion of the airfoil forming a conventional slat was not removed for the test. The model leading edge was configured in this manner to simulate a slat design consisting of a flexible plate with folding nose that would extend from the airfoil lower surface immediately aft of the leading edge.

With the extended-wing configuration, the slats were mounted in two spanwise segments, from the body to the inboard side of the nacelle (one segment) and from the outboard side of the nacelle to the wingtip. When the model was modified into the retracted-wing configuration, the inboard slat was removed and a highly cambered, bulbous-nose, leading-edge flap was installed in the remaining space. This Krueger-type flap is illustrated in Figure 3.2-11.

3.3 Fuselage Geometry

The half fuselage used for the test can be seen in Figures 2.3-1 and 2.3-2. This midwing body had a width comprising 13 percent of the retracted span with a shape generally representative of a VTOL design that employed a fan-in-nose for longitudinal trim. The vertical tail served as a platform for attaching the downwash rake.

Since only the wing was mounted on the balance, the wing/body juncture hole was made approximately 0.125 inch oversize to prevent interference between the wing and fuselage. The fuselage was bolted to a yaw table through an 0.75-inch-thick base plate with a 0.25-inch space between the plate and the table. Thus, a one-inch gap existed between the bottom surface of the fuselage and the ground board. As shown in Figure 3.4-2, the balance was protected from the free stream by a cylindrical fairing.

3.4 Model Installation

As mentioned previously, the test was conducted in the 20 by 20-foot test section of the Boeing Vertol V/STOL tunnel. See Figure 3.4-1 for a detailed schematic of the tunnel.

Two test-section configurations were used for this test, namely open throat and slotted throat. Both side walls were stowed in pits and the ceiling was raised to open up the 67-foot-diameter plenum for hover testing using the open-throat configuration. The slotted walls and ceiling are usually used for forward-flight testing to minimize wall effects.

The model was installed in the tunnel as shown in Figure 3.4-2 for the extended-wing configuration and in Figure 3.4-3 for the retracted-wing configuration. A ground board 59 inches above the tunnel floor served as a plane of symmetry, as shown in Figure 2.3-5. The four-component balance mounted at the base of the wing structure, below the ground board, was attached to a cylindrical post which supported the model to the tunnel yaw mechanism. All yaw table driving gears plus motor are located below the tunnel floor. High-pressure air to the blown-air pod was routed in two pipes along opposite sides of the post mount, around the balance in large loops, and then into the hollow spar of the wing. The entire assembly between the platform and the tunnel floor was enclosed within a cylindrical fairing that permitted the model to be yawed ± 90 degrees in angle of attack. The 17-inch loops (measured from the model axis) of the air pipes around the balance dictated a fairing diameter of approximately 3 feet. Balance calibrations verified that the airpipe routing virtually eliminated any balance interactions due to high-volume air passage.

The wing was retracted for transition testing by removing the inboard slat, the inboard spanwise segment of the flap, and a cylindrical section of the post mount that matched the length of the inboard flap. Thus, the wing was essentially lowered into the wing/body juncture hole.

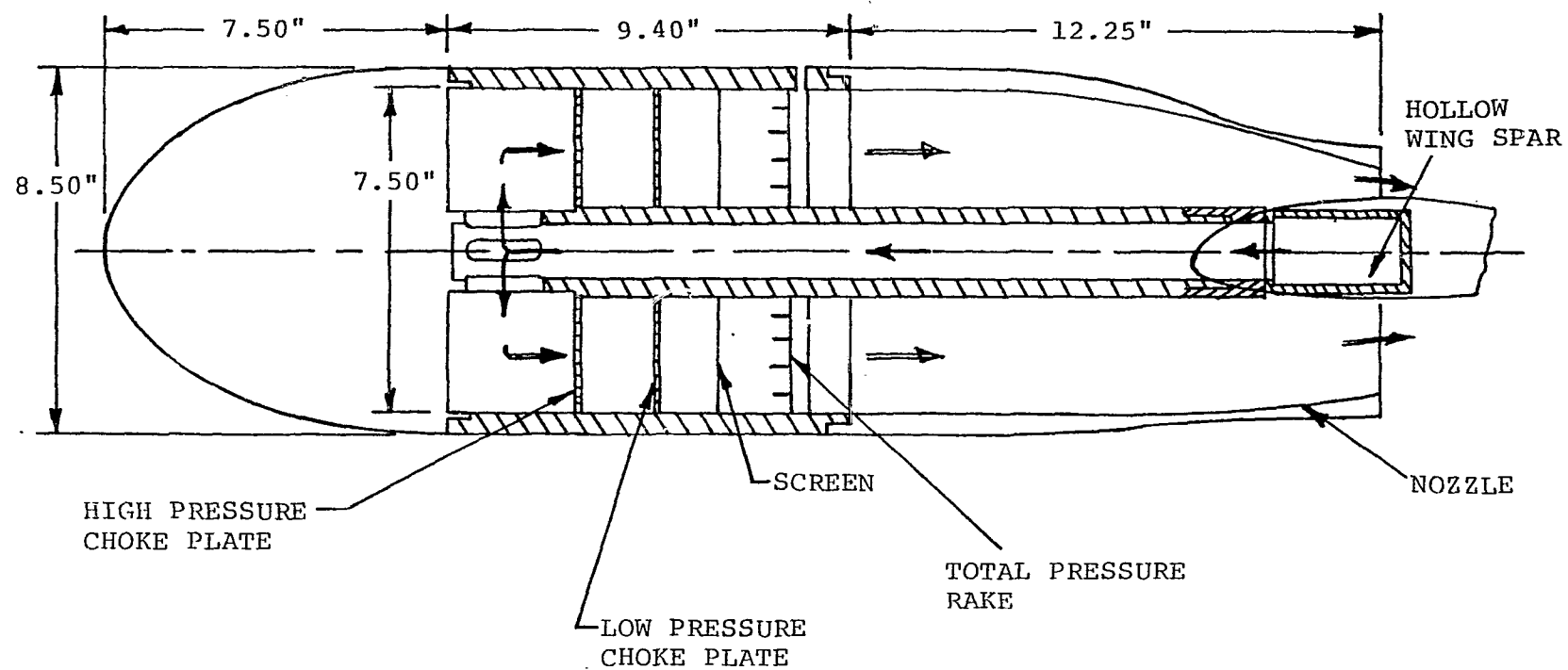


Figure 3.1-1. Air Pod

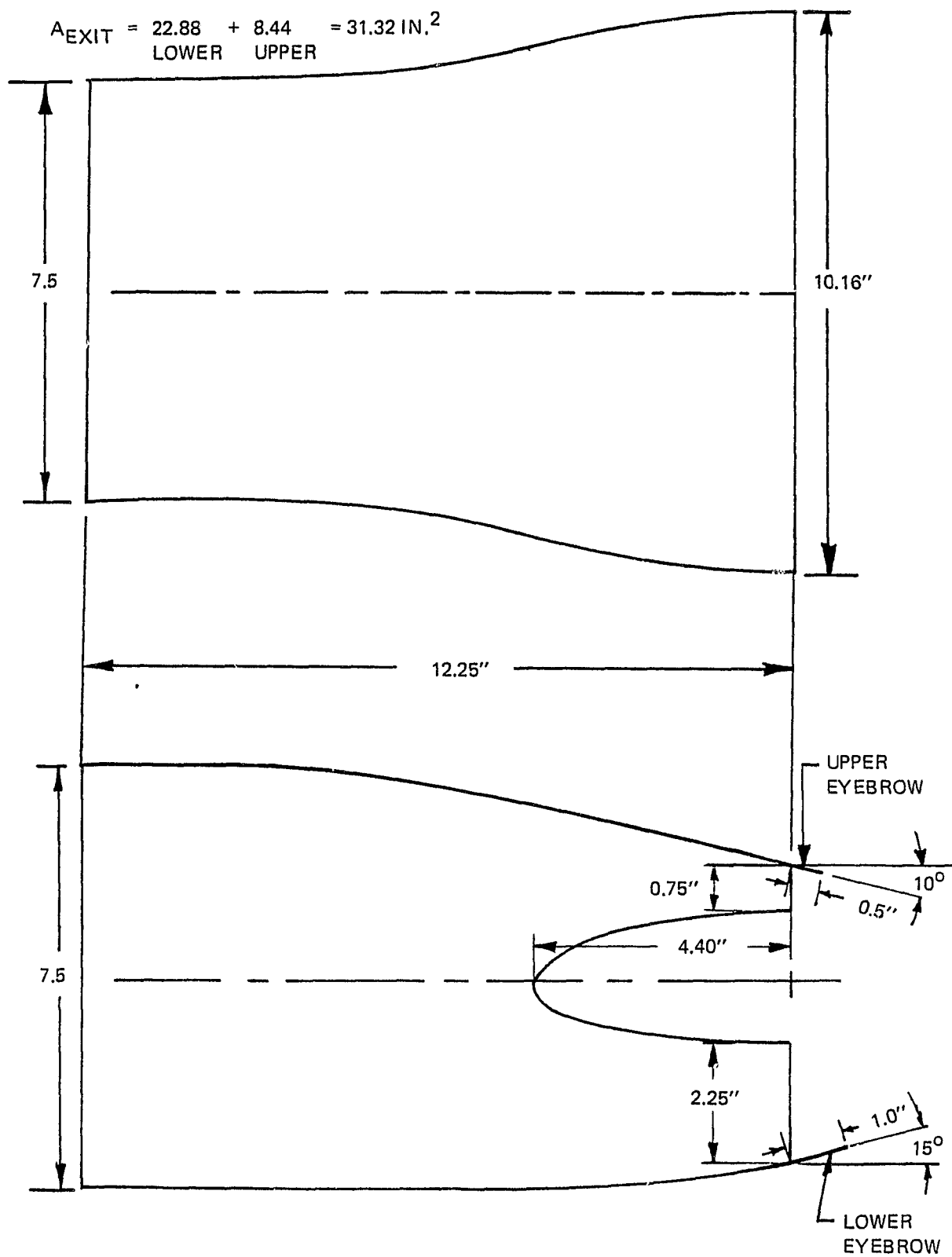


Figure 3.1-2. Combined-Surface-Blowing Nozzle

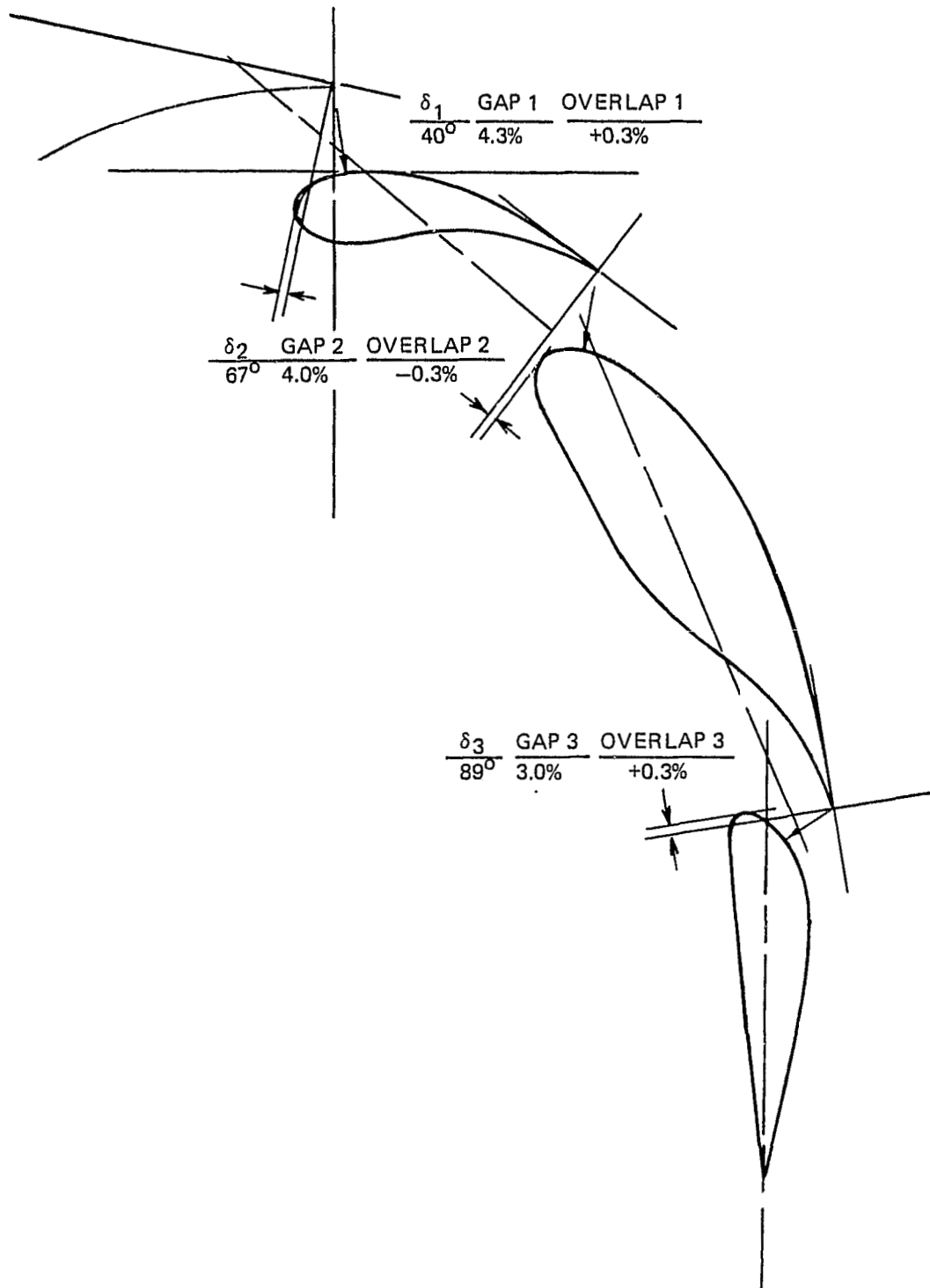


Figure 3.2-1. Flap A Configuration with $\delta_f = 90^\circ$

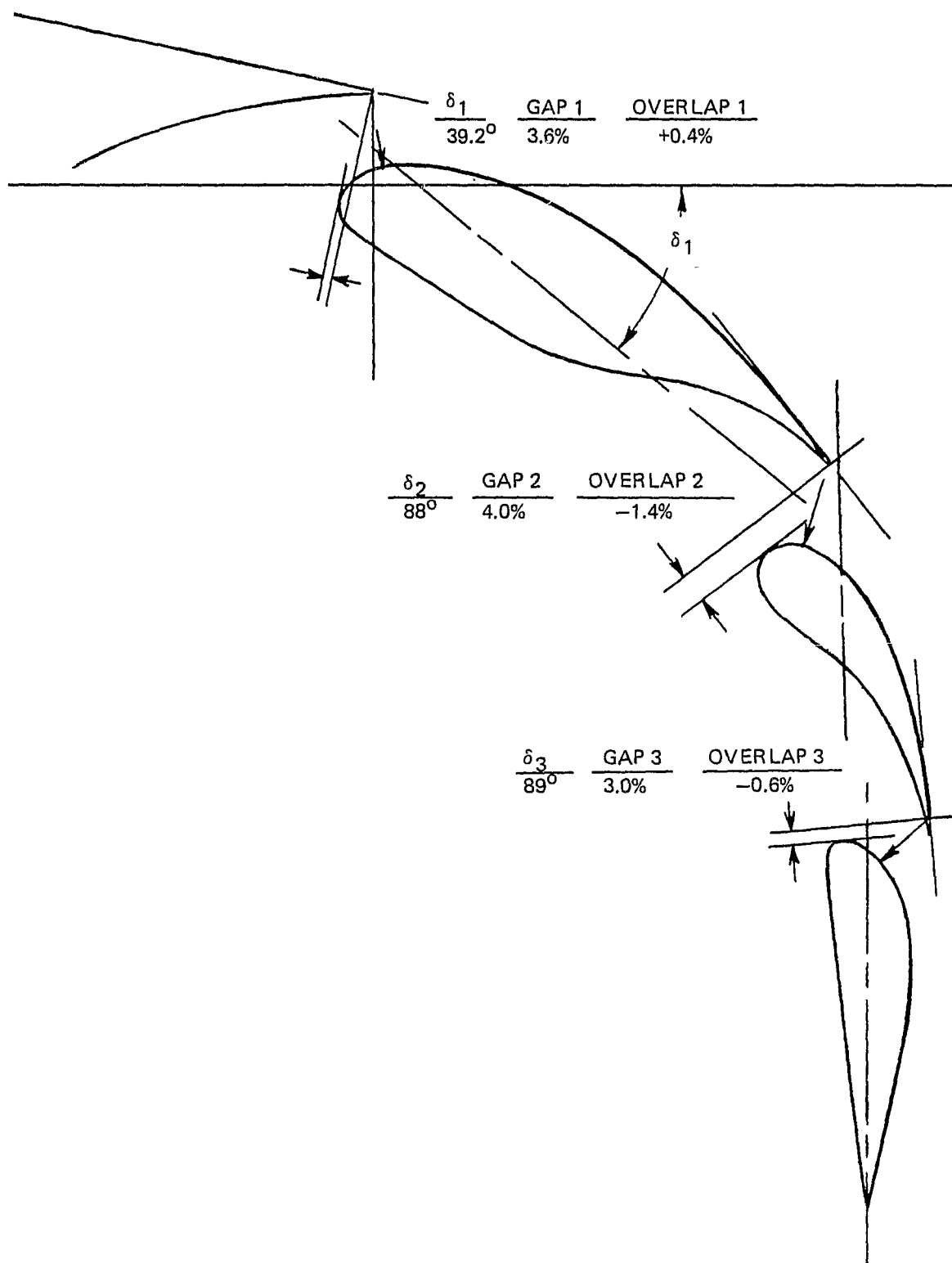


Figure 3.2-2. Flap B Configuration with $\delta_f = 90^\circ$

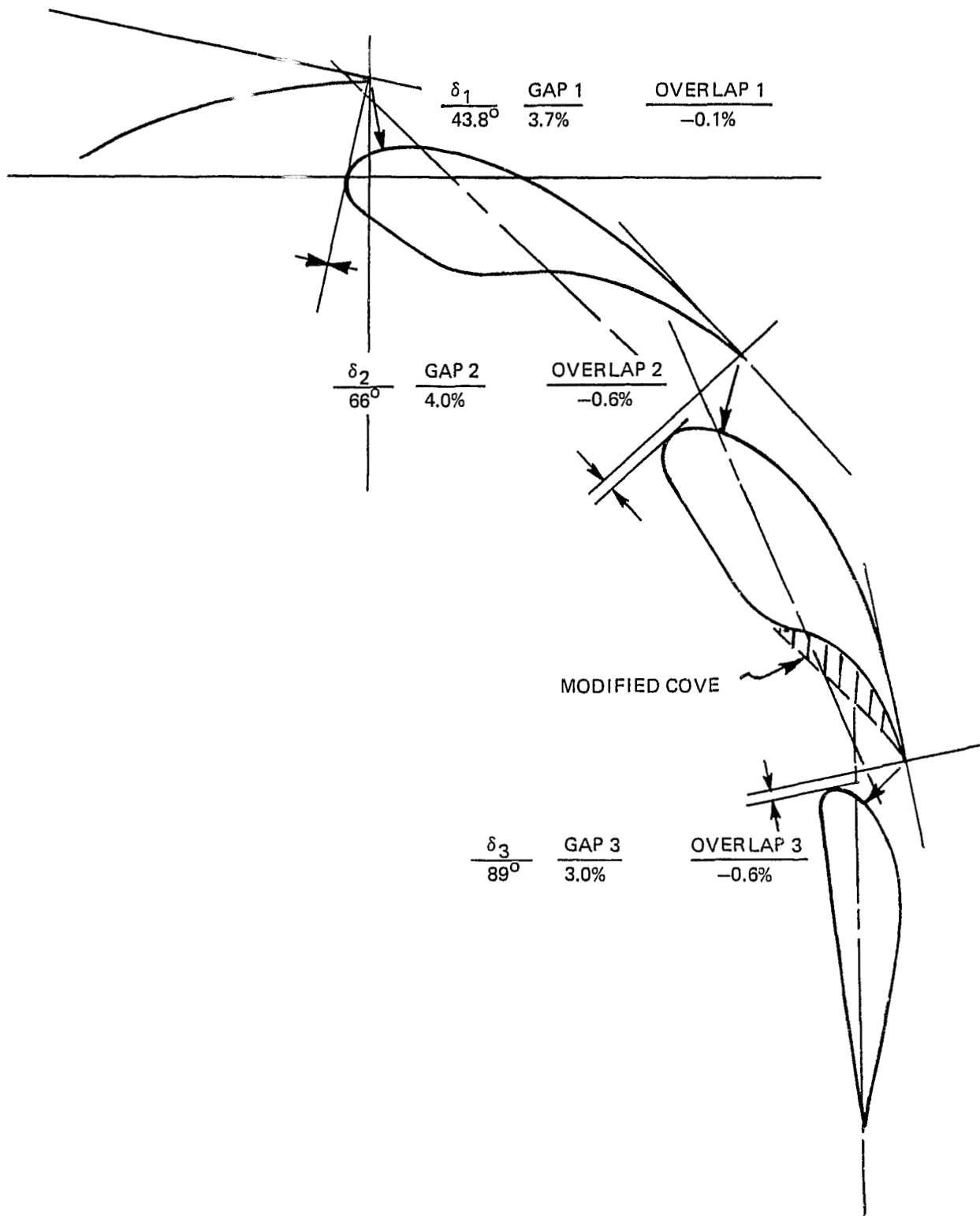


Figure 3.2-3. Flap C Configuration with $\delta_f = 90^\circ$

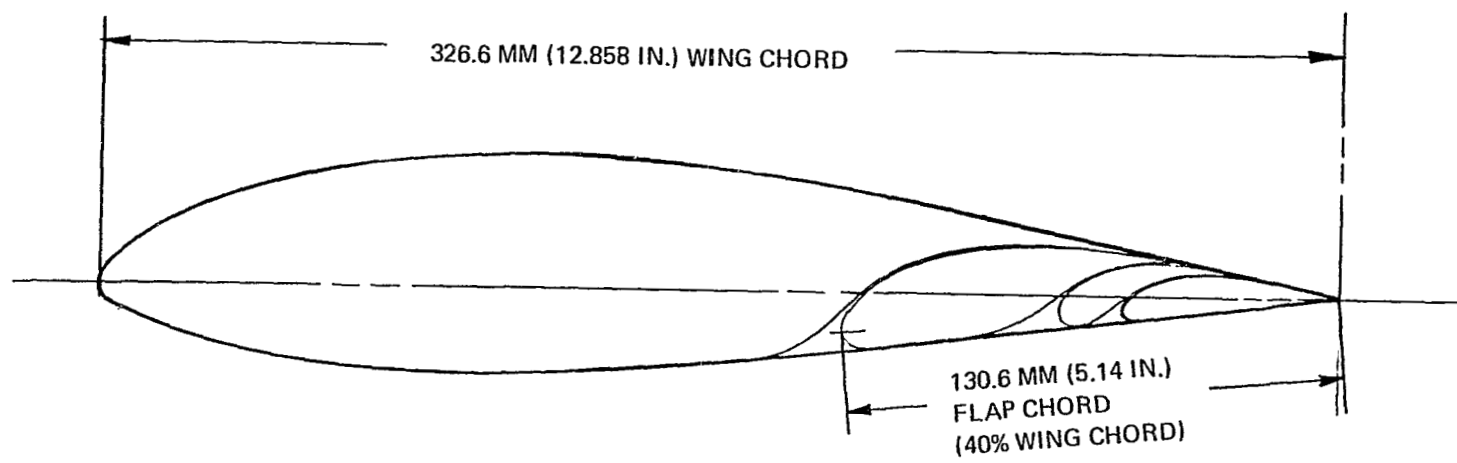


Figure 3.2-4. Wing and Flaps in Nested Configuration

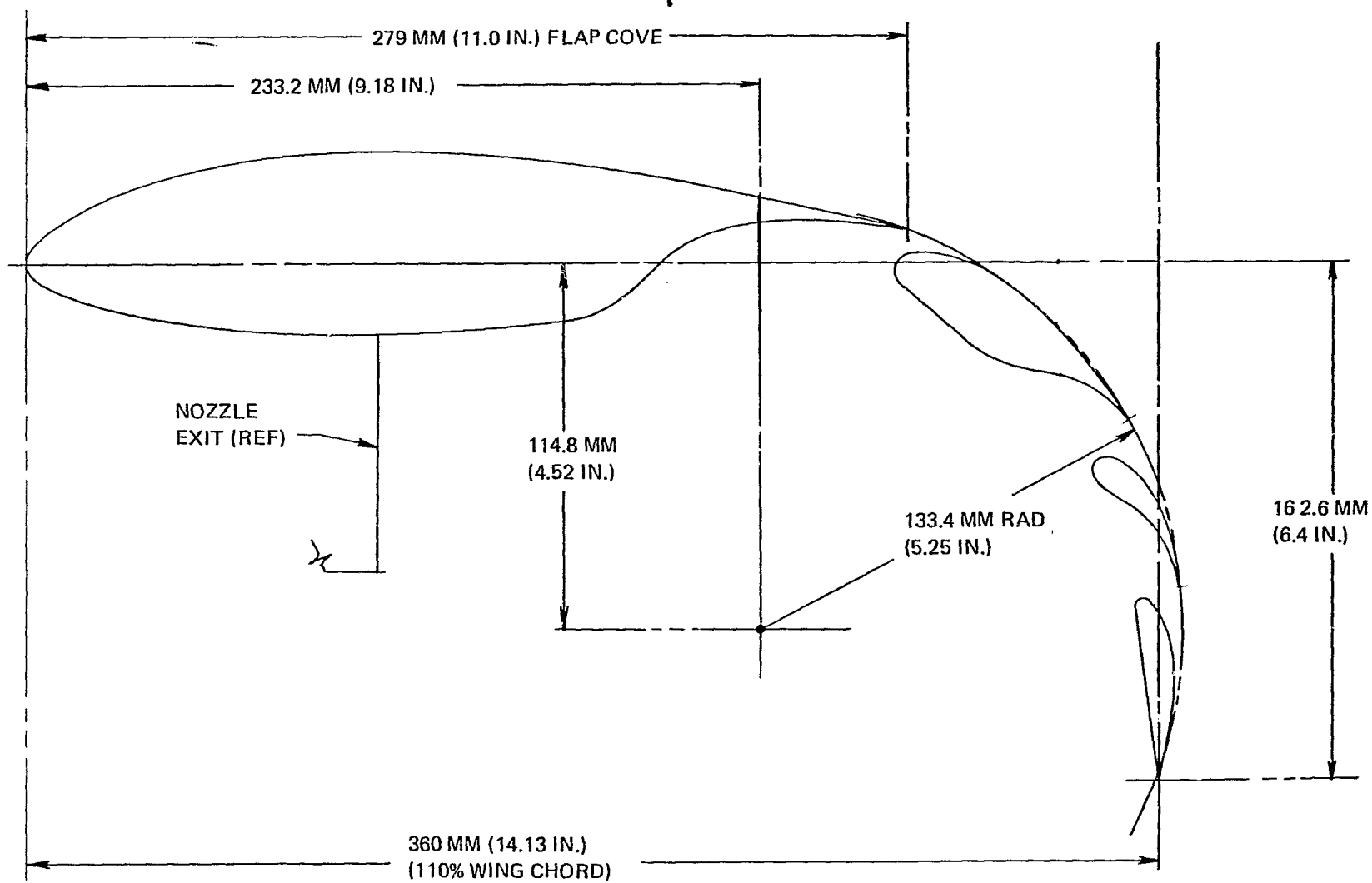


Figure 3.2-5. Wing and Flaps in Extended Configuration

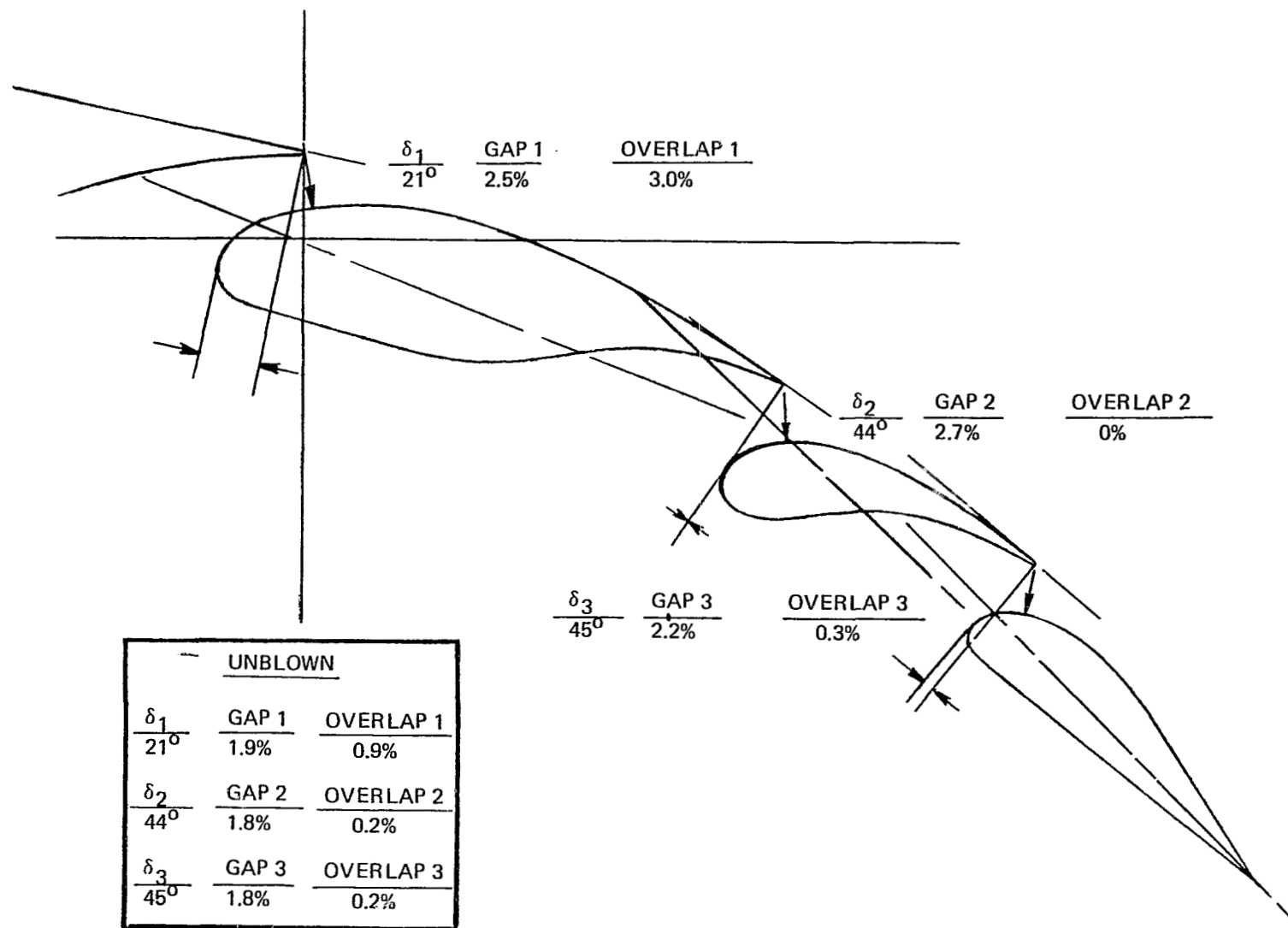


Figure 3.2-6. Flap B Configuration with $\delta_f = 45^\circ$

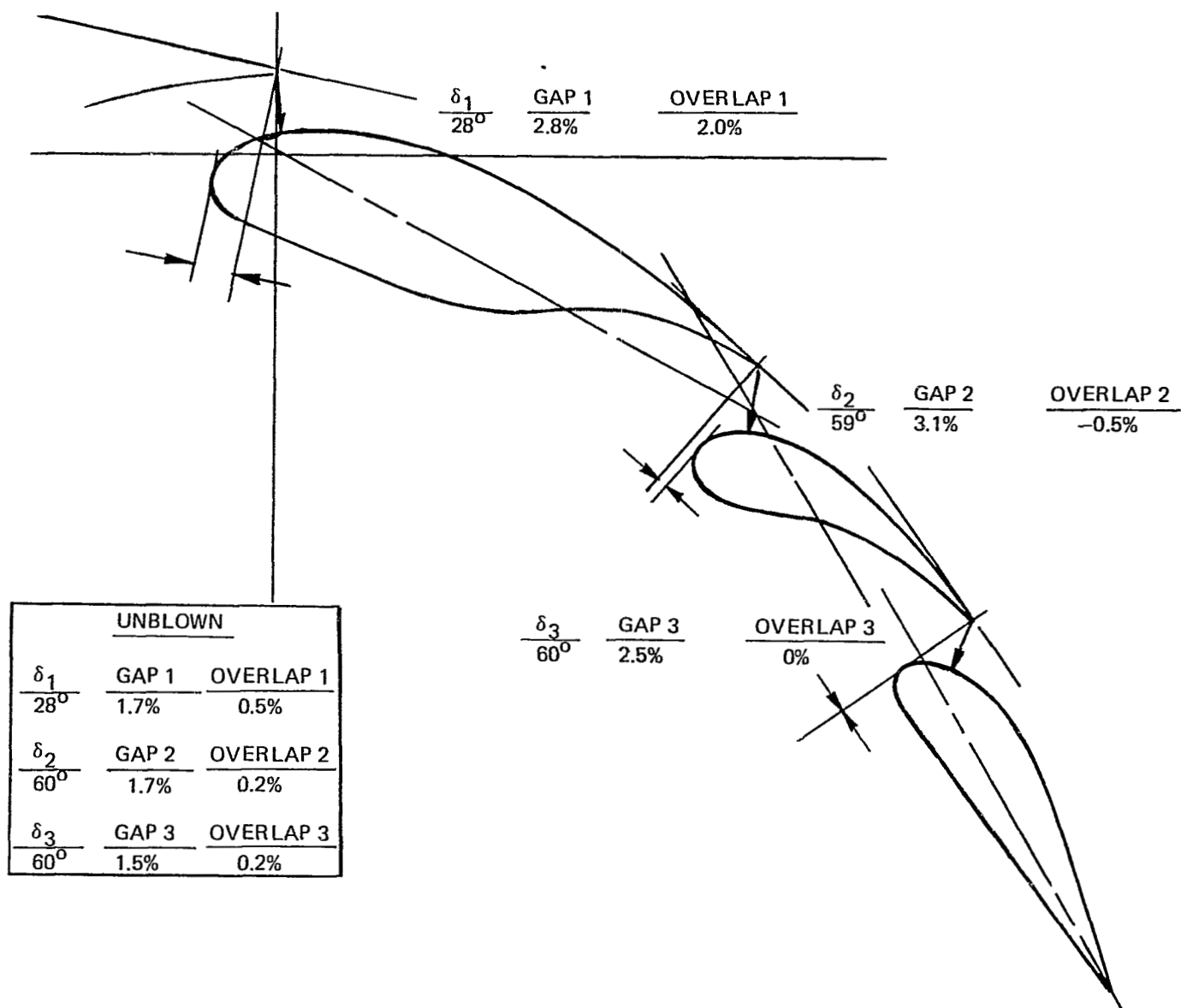


Figure 3.2-7. Flap B Configuration with $\delta_f = 60^\circ$

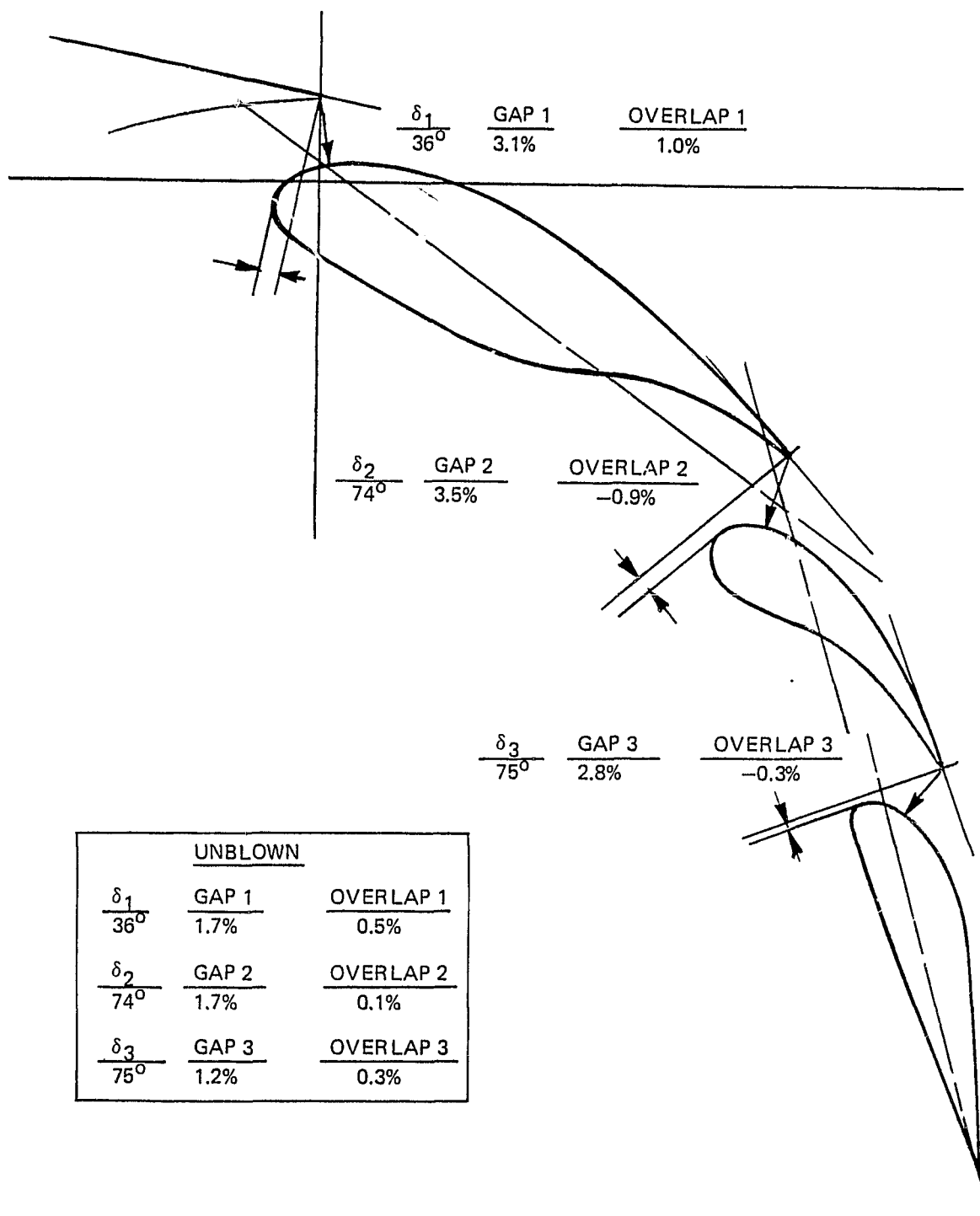


Figure 3.2-8. Flap B Configuration with $\delta_f = 75^\circ$

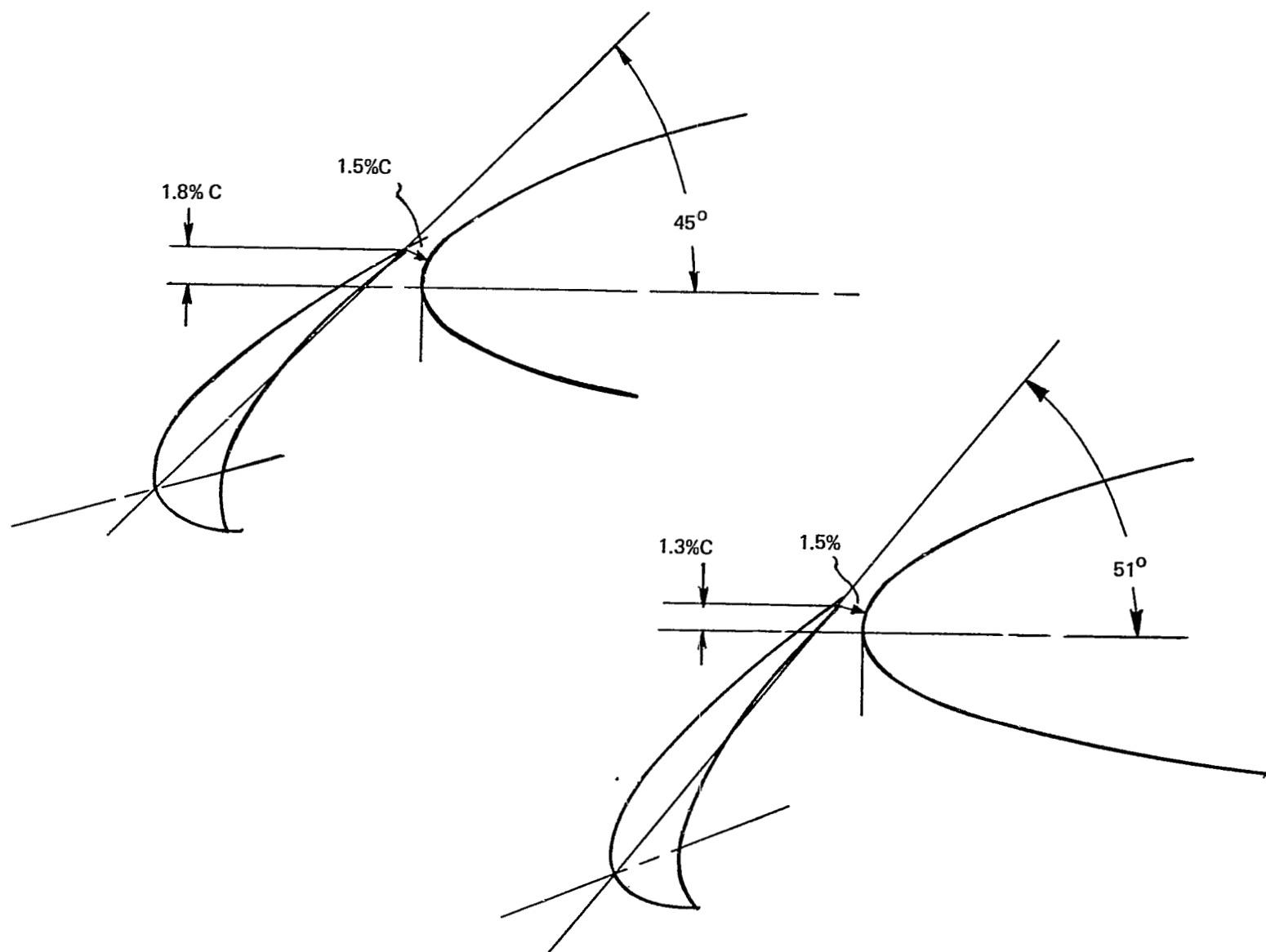


Figure 3.2-9. Slat Configurations

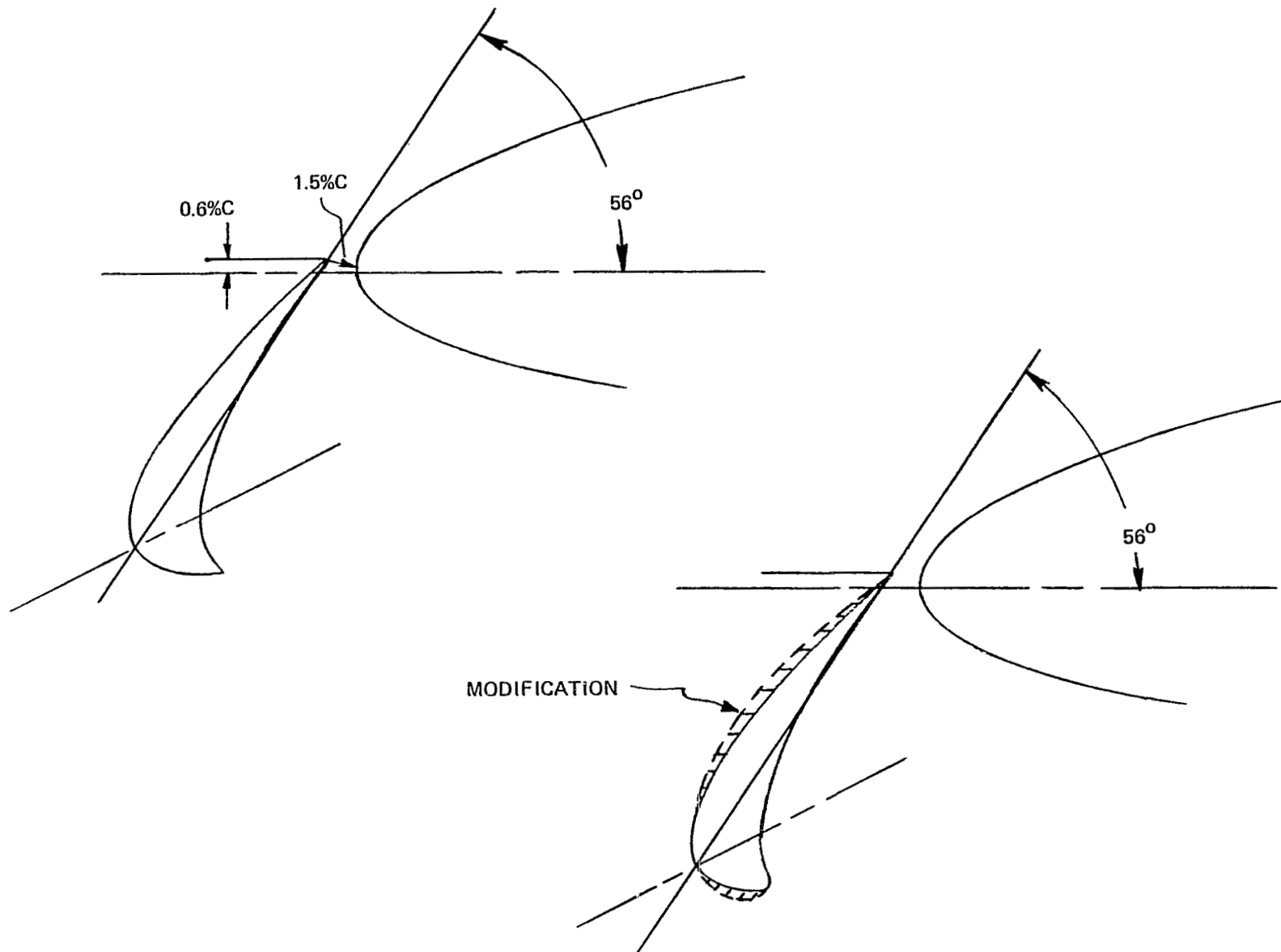


Figure 3.2-10. Slat Configurations

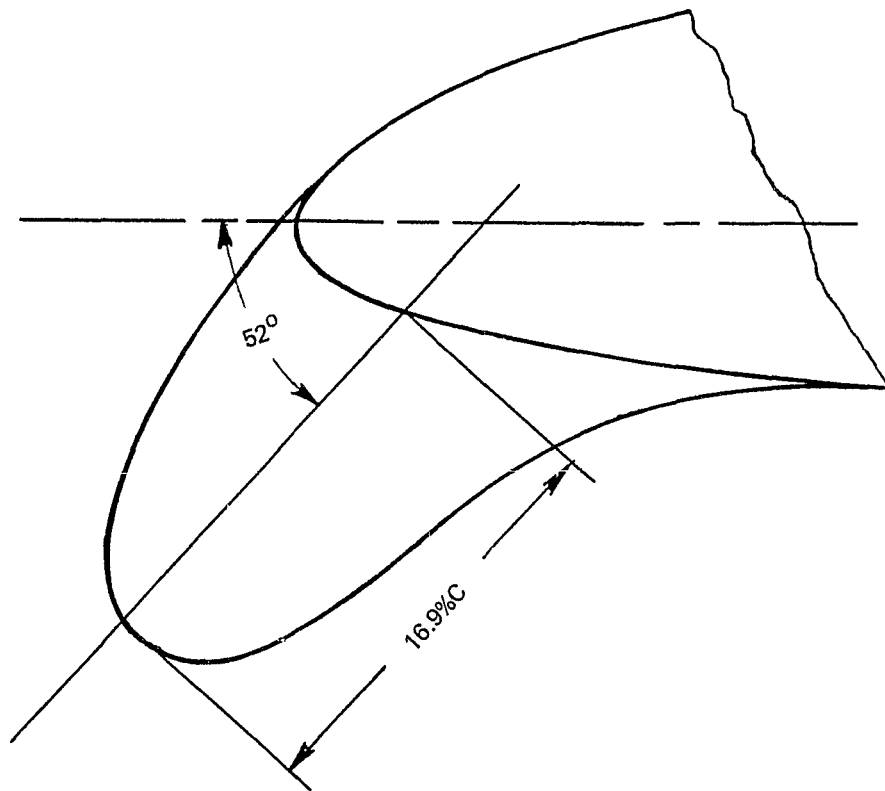


Figure 3.2–11. Leading-Edge Droop-Nose Krueger Flap

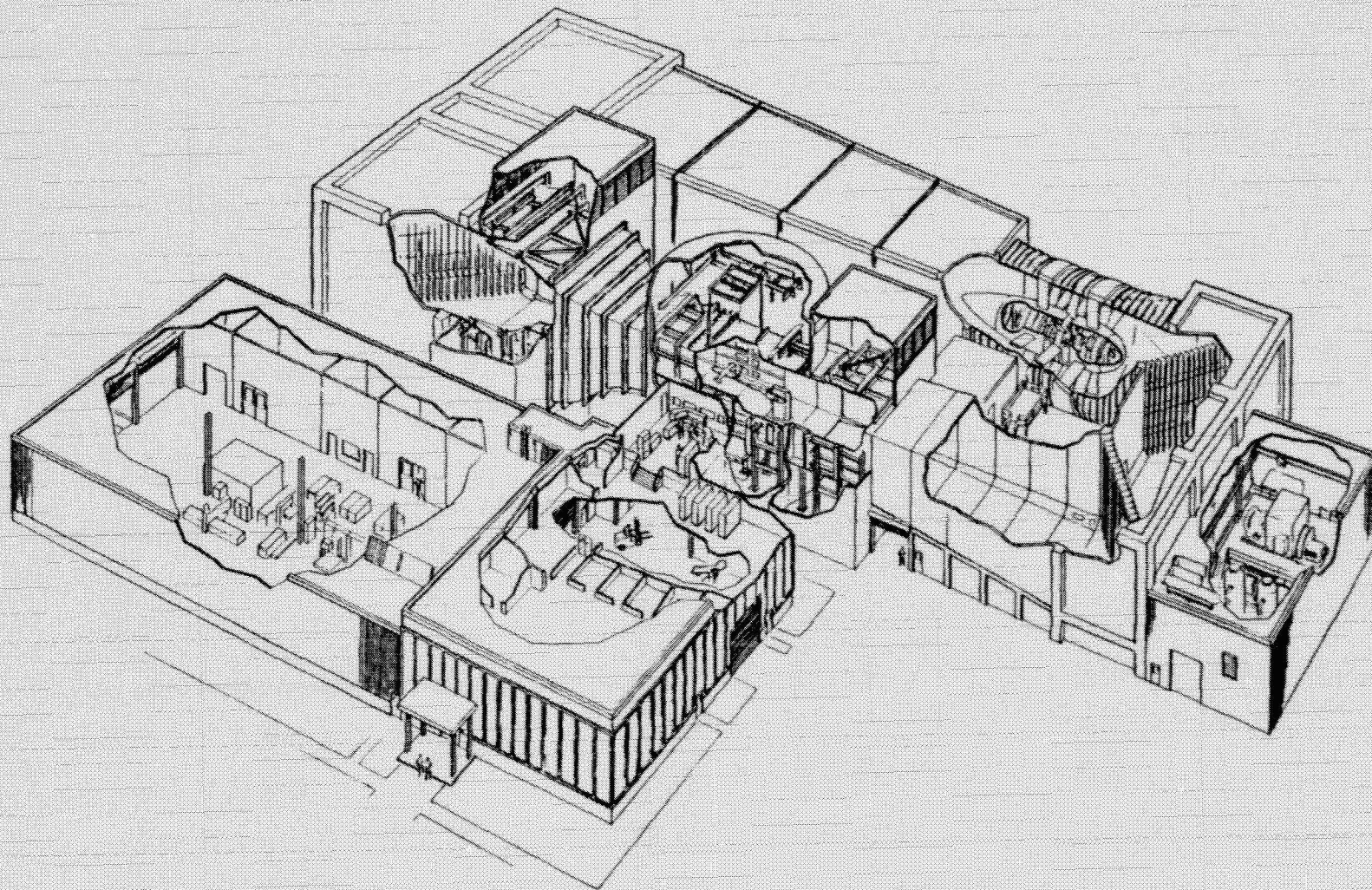


Figure 3.4-1. Schematic of Boeing V/STOL Wind Tunnel

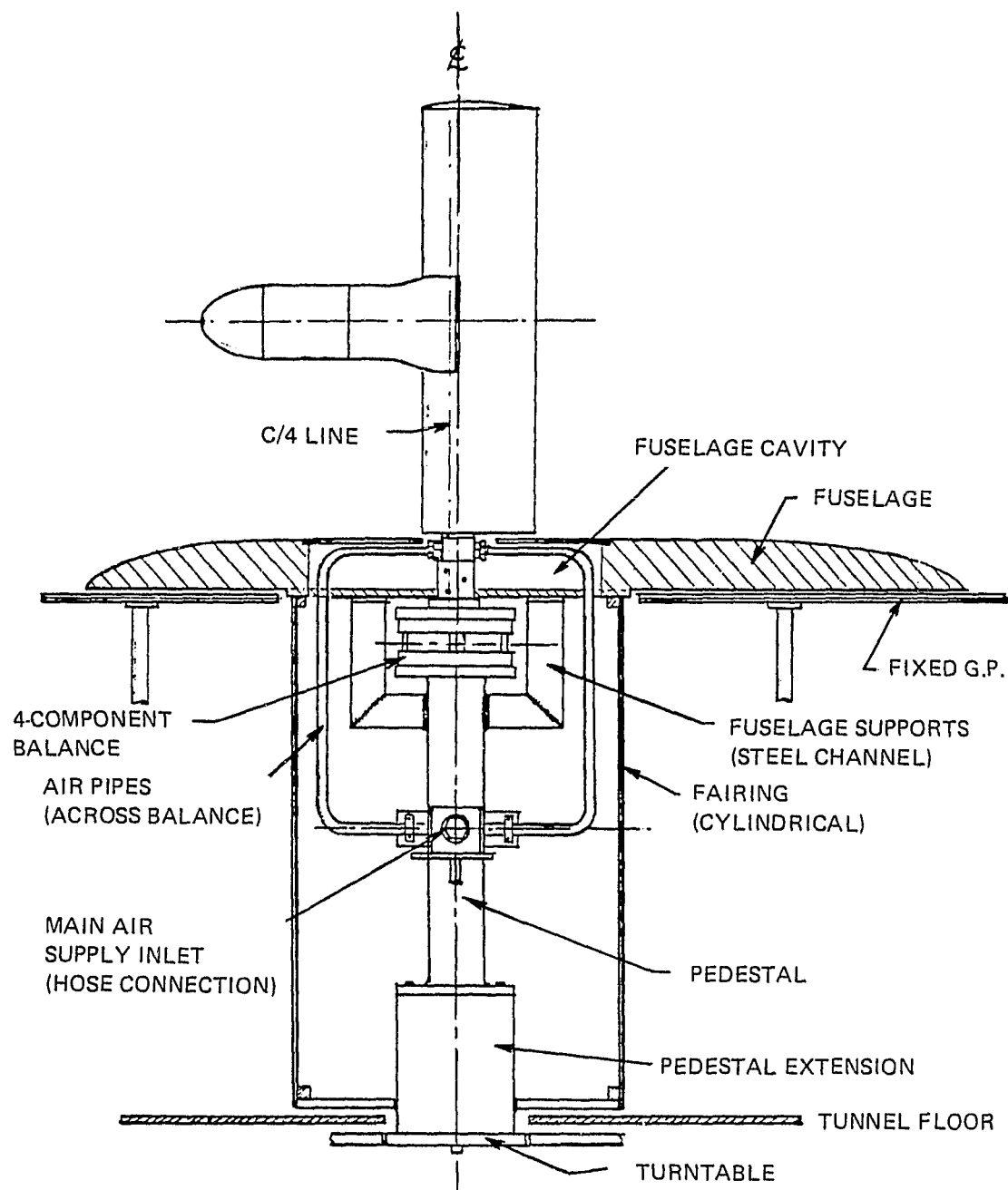


Figure 3.4-2. Model Installation with Extended Wing

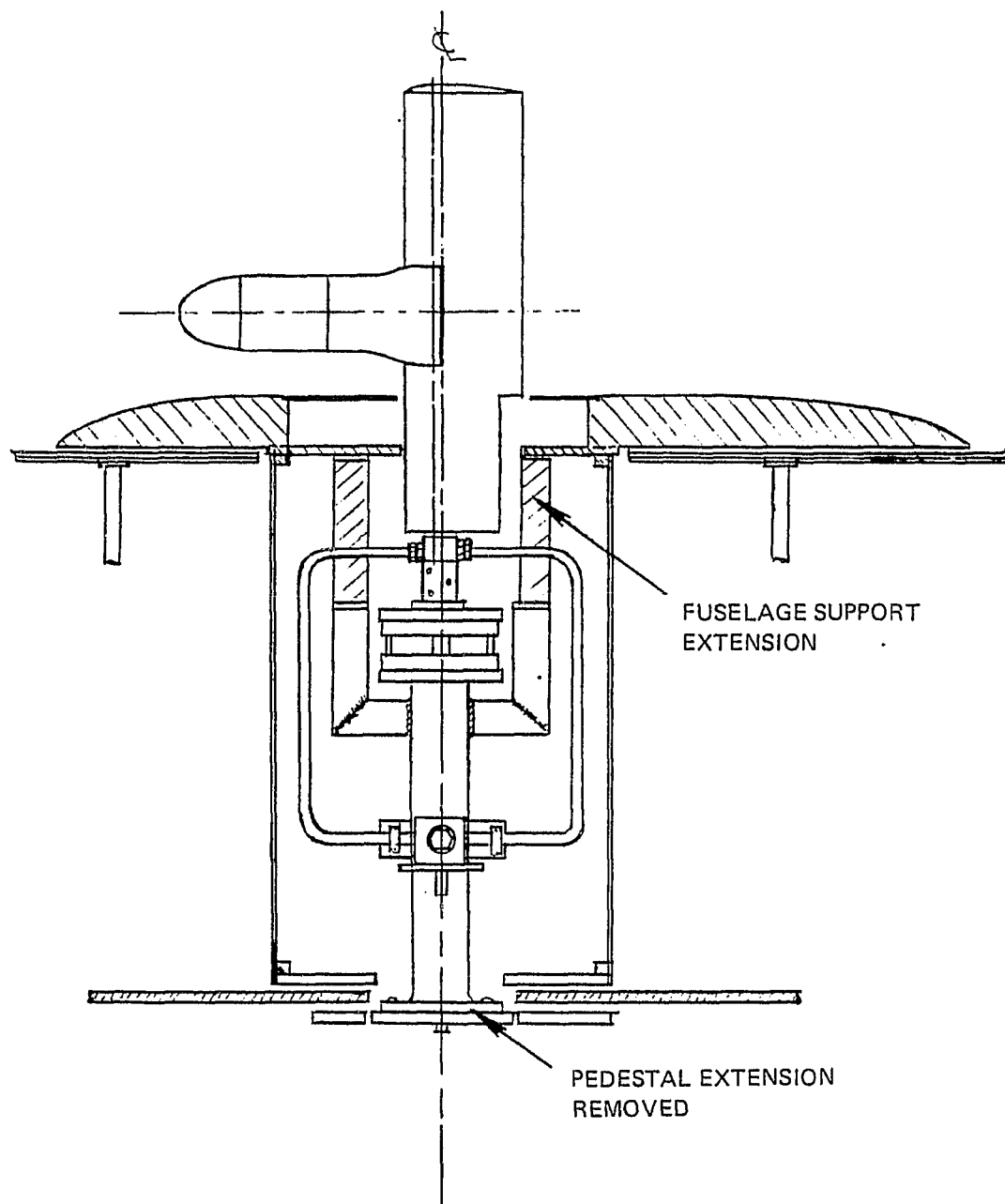


Figure 3.4-3. Model Installation with Retracted Wing

4.0 INSTRUMENTATION AND EQUIPMENT

4.1 Model Instrumentation

In addition to the ASME nozzle installed in the tunnel auxiliary-air-supply system for measuring mass flow through the air pod, model instrumentation consisted of the following items:

a. Four-Component Strain-Gage Balance

This balance was inserted between the base of the wing structure below the ground board and the post mount with its axis parallel to the wing-chord line. Thus, yawing the model turned the balance with the wing. Components measured by the balance were normal force, axial force, pitching moment, and rolling moment.

b. Air-Pod Total Pressure

The pod total pressure, used to calculate pod pressure ratio and derive other parameters such as thrust recovery, was measured with a 16-tube rake installed in the cylindrical section of the pod just forward of the nozzle. The 16 pressure pickups were averaged by manifolding the pitots into a single outlet tube. The position of the pressure rake is shown in Figure 3.1-1.

c. Air-Pod Total Temperature

A thermocouple was installed on the air-pod pressure rake to measure the total temperature required for calculating the nozzle coefficients during the calibration runs and the corrected weight flow during the transition testing.

d. Downwash Rake

The downwash rake mounted at the top of the vertical fin for downwash-angle and total-pressure measurements during forward-flight runs consisted of a swiveling barrel with four vaned probes to align the rake along the local velocity plus three pitot tubes. These pitot tubes were plumbed together to provide an average pressure. Downwash angle was measured by a rotary potentiometer mounted on the rake shaft. Specific dimensions are presented in Section 7.3.4 and a drawing of the rake is shown in Figure 7.3-25.

4.2 Data-Acquisition System

The automatic data system can accept up to 120 channels from the model and the tunnel itself. These signals are routed to an IBM 1800 computer for processing and on-line data reduction. The computed results are tabulated by a line printer point by point during a run or can be stored for a postrun tabulation. Six selected variables can be plotted on-line by X-Y plotters. Final data is stored on magnetic tape for additional posttest plotting requirements or reprocessing.

A digital display of any nine channels simultaneously is also available during testing for monitoring purposes. Each monitoring channel can display predetermined prime quantities in engineering units or coefficients that are calculated by separate software and continuously updated during each run. The parameter displayed in each channel can be switched through a control box to a variable more appropriate for a particular run. As a result of the continuous update, a model is usually flown with the aid of a monitoring channel, for example, the calculated ASME air-pod mass flow during the static-performance testing and gross-thrust coefficient during the transition runs.

5.0 DATA REDUCTION

The test data was reduced on-line and presented in both graphical and tabular format to aid in monitoring and conducting the test. The final data plots presented in this report were produced on a CALCOMP 1627 drum plotter after the test completion. The noise data was recorded on a Honeywell 5600C, four-track, WBFM, one-inch tape recorder operated at 30 ips and was analyzed on a General Radio 1925 multifilter and 1926 multichannel detector with each test record integrated over a 32-second period. Force and moment data was reduced on an IBM 1800 computer and was identified as belonging to one of the following types of data: calibration, static test, or transition test.

5.1 Calibration

During the calibration runs, made with a retracted flap, calibration curves were developed for use in subsequent testing. The ideal airflow was computed from the measured air-pod total pressure and temperature and was compared with the actual airflow, obtained from the air-supply-system instrumentation, to obtain nozzle-discharge coefficient. Similarly, the computed value of ideal thrust was compared with actual thrust measured by the four-component balance to obtain the nozzle-velocity coefficient. These coefficients were then curve-fitted as a third-order function of pressure ratio and the curve-fitting equations were used during subsequent testing to determine the reference thrust.

5.2 Static Testing

During static testing, the discharge and velocity coefficients were determined from the calibration curves at the appropriate pressure ratio. From these calculations and from the measured air-pod total pressure and temperature, the jet Mach number, ideal thrust, and reference thrust levels were determined. The thrust recovery was then determined by dividing the resultant force, as measured on the balance, by the reference thrust.

5.3 Transition Testing

In the transition test phase, the jet Mach number and the pressure ratio were computed from the measured airflow and the air-pod total pressure and temperature. From these calculations, the gross thrust and the thrust coefficient were then computed and displayed on overhead monitors in the test-console area. All aerodynamic coefficients were computed and calculations were made of representative aircraft performance in terms of steady-rate-of-climb capability. The calculation of axial-force coefficient, C_x , included an adjustment to represent the inlet momentum drag of a real fan. The inlet momentum drag coefficient was represented as:

$$\Delta C_x = - \sqrt{\frac{2 A_{eff}}{S_{Ref}}} C_j .$$

The slotted-wall configuration of the Boeing V/STOL wind tunnel was specifically designed to eliminate the necessity of applying wall corrections for V/STOL configurations. The design was based on an experimental program of various wall configurations and the effectiveness of the slotted walls in reducing wall effects has been verified by subsequent experimental and analytical work. Therefore, no wall corrections were applied to the experimental data of this program. However, the flow on the tunnel wall was monitored by tuft observations to ensure that flow breakdown did not occur.

6.0 TEST PROCEDURE AND TEST CONDITIONS

6.1 Nozzle Survey

At the beginning of the static-test phase, a series of nozzle-flow survey runs were made to determine flow uniformity at the exit of the upper- and lower-surface nozzles. A pitot-static probe was mounted on a remotely controlled traverse mechanism at the exit of the nozzle for these surveys. Figure 6.1-1 shows the results of the survey in terms of total-pressure deviations relative to the mean total pressure during the measurements. The runs were made at an air-pod pressure ratio of approximately 1.20, which required 9.5 lb/sec of airflow from the tunnel air supply. Pressure uniformity, as seen in Figure 6.1-1, was found to be generally within 1 to 2 percent.

6.2 Static-Testing Procedure

Static-test runs were made by varying air-supply pressure to the model over the range of approximately 200 psi to 750 psi. This provided between 4 and 14 lb/sec of airflow and nozzle-pressure ratios from approximately 1.04 to 1.45. Both thrust recovery and thrust-deflection angle were sensitive to pressure ratio, with slight reductions in both parameters generally occurring as the pressure ratio was increased. Analysis of the data and flap-configuration optimization was conducted at a baseline pressure ratio of 1.2. This represents the approximate design value of pressure ratio in hover for the nozzle size tested (nozzle size relative to wing size). This relationship is shown in Figure 6.2-1.

The static-phase testing was begun with the Flap B configuration. A series of runs were made to examine the effects of the individual slot gaps and overlaps and of the flap-element deflection angles on thrust recovery and thrust-deflection angle at the baseline pressure ratio of 1.2. From these sensitivity runs, a new combination of flap-element positions was identified and tested for the Flap B configuration. Following Flap B testing, additional optimization testing was conducted on the A and C flaps.

6.3 Noise-Measurement Procedure

6.3.1 Instrumentation and data acquisition. — Acoustical measurements of the CSB model were recorded during the static-performance testing in the test section of the tunnel with the ceiling and walls removed. Half-inch condenser microphones and a one-inch 14-track FM tape recorder were used to record the data.

Eleven microphones were mounted in the plane of the air-pod nozzle on a 2.29-meter (7.5-foot)-radius circle, as shown in Figure 6.3-1. The relatively short microphone distance was used in order to avoid reflecting surfaces and to assure that the direct radiated signal was larger than the reverberant signal. Ten microphones were positioned under the wing at azimuth locations from 0 degrees to 180 degrees in 20-degree increments, with one microphone located above the wing at 270 degrees.

The model-mounting platform was surface-treated with one-half-inch fiberglass acoustical boards to minimize any broadband, high-frequency sound reflection to the microphones which were located approximately 0.76 meter (30 inches) above the plane. All microphones were positioned so the axis of the cartridge was directed toward the center of the model nozzles.

To reduce any air-system-supply noise, the air pod was wrapped with a sound-attenuating acoustical blanket. The electronic system for monitoring and recording the model noise consisted of the following:

- Bruel and Kjaer (B&K) type 4133/2615 microphone systems fitted with the B&K type UA 0386 aerodynamically shaped nose cones (Figure 6.3-2), microphone power supplies B&K type 2801, and extension cables B&K type AO 0029, in 30-meter (100-foot) lengths.
- Dynamics Corporation Model 7704/PG preamplifier system and California Instruments Model 7211 monitoring oscilloscopes.
- Honeywell 5600C, 14-track, wideband FM, one-inch magnetic-tape recorder operated at 30 ips; 11 tracks recorded the microphone outputs, 1 track recorded a time-code signal, and 1 track voice identification. This recording instrumentation is shown in Figure 6.3-3.

All recorded data was integrated over a 32-second period and analyzed by one-third-octave frequency band using a General Radio 1925 multifilter, 1926 rms detector, and 1523 graphic-level recorder. Selected test runs were analyzed using a Nicolet UA500A real-time analyzer and recording the results with an oscilloscope and Polaroid scope camera to identify pure tones in the noise data. Examples of this data are presented in Section 7.2.

6.3.2 Instrumentation calibration procedures. — Prior to the test period, all microphones and cables were frequency-calibrated using the B&K electrostatic actuator, Type UA 0033. A typical calibration chart for one of the microphones is shown in Figure 6.3-4. Applying the free-field correction, for the Type 4133 microphone cartridge with a UA 0386 nose cone, to the calibration curve provides a relatively flat response from 20 to 10,000 Hz, as indicated in the figure.

All microphones were periodically calibrated at 114 db rms (ref. 2×10^{-5} n/m²), 1000 Hz, using a Columbia sound-level calibrator, Type SPC-10. The tape recorder was adjusted for a flat frequency response from 0 to 20,000 Hz prior to the test program.

6.3.3 Test-area calibration procedures. — Due to the semireverberant characteristic of the wind-tunnel plenum/test section, an acoustical calibration of this test area was performed to allow for the prediction of free-field noise levels from the wind-tunnel measurements. The calibration procedure consisted of generating a broadband frequency, random-noise field in both the open tunnel section and in an open field (out of doors). A high-fidelity speaker (University

CLC system) representing the point noise source was located in the test area at the exact position of the CSB model as shown in Figure 6.3-5. Noise data was then recorded at each microphone location for each repositioning of the speaker with its axis of penetration directed toward that microphone.

The output of the speaker was controlled by monitoring the voltage output of the audio-power amplifier. This procedure was then repeated in an open field with the identical speaker/microphone array, which then provided a comparison of the wind-tunnel and open-field noise spectra. For each microphone position, an amplitude (as a function of one-third-octave band frequency) correction for free-field measurement was established. A typical wind-tunnel reverberation correction is shown in Figure 6.3-6. The correction for each microphone was applied to the noise data.

6.4 Transition-Testing Procedure

At the completion of the static and noise phases of testing, the wind tunnel was reconfigured for the transition part of the test. The walls and ceiling were reinstalled in the slotted-wall configuration. The balance and pedestal assembly under the fixed ground plane were isolated from the tunnel airflow by a cylindrical sheetmetal fairing.

The model was tested in both the extended-wing and retracted-wing configurations. Much of the initial exploratory testing, such as the effects of the air pod and slat-effectiveness studies, was done with the extended wing. However, the majority of aerodynamic-performance testing over the full range of flap deflections, from 45 to 100 degrees, was conducted with the retracted wing since it more closely represented the actual nacelle-body arrangement visualized for an airplane.

Two types of runs were made for aerodynamic performance:

- Variations in tunnel dynamic pressure, q , for the condition $\alpha = 0^\circ$. As dynamic pressure was changed, the air-pod thrust was also varied to maintain specified levels of thrust coefficient, C_j .
- Angle-of-attack sweeps at specified values of C_j and at constant q .

The dynamic-pressure-variation runs were made to examine the effects of jet Mach number on the model aerodynamic characteristics. As the tunnel q and thrust were increased at constant C_j , the Mach number of the jet would also increase. It was determined that the lift was sensitive to Mach number, as discussed in Section 7.3.3. Thus, the tunnel dynamic pressure used during the α -sweep runs was selected as a scheduled function of C_j and flap deflection, approximating the schedule used by an airplane in steady flight. The schedule used, shown in Figure 6.4-1, was determined from a calculated steady climb-speed map for an airplane using the CSB lift/propulsion system. In Figure 6.4-1, the range of flight dynamic pressures shown varies from maximum resultant force (minimum speed) to the lowest angle of attack tested, $\alpha = -4^\circ$ (maximum speed).

The tunnel speed schedule chosen for the α -sweep runs provided total model loads consistent with the balance allowables. Dynamic-pressure-variation runs were made at combinations of q and C_j up to the capability of the balance. The test envelope is shown in Figure 6.4-2.

Flow-visualization runs were made using both tufts and China clay (mixture of kaolin and kerosene). Although the effects of the tufts on the model aerodynamics were not significant during transition testing, the high jet velocity behind the air pod quickly tattered any tufts in the jet region. As a result, the majority of these runs were made with the tufts removed.

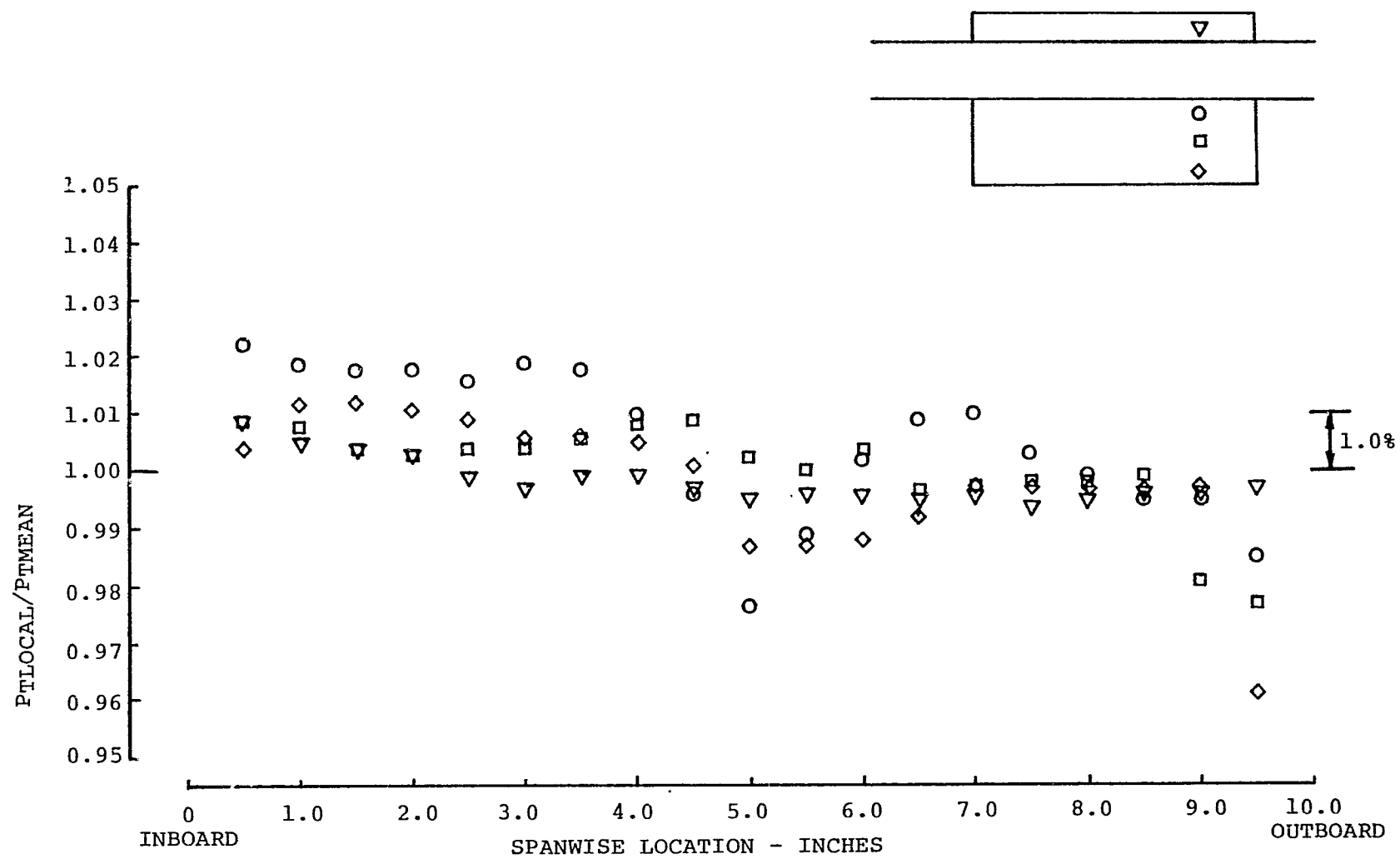


Figure 6.1-1. Combined-Surface-Blowing Nozzle-Exit Survey

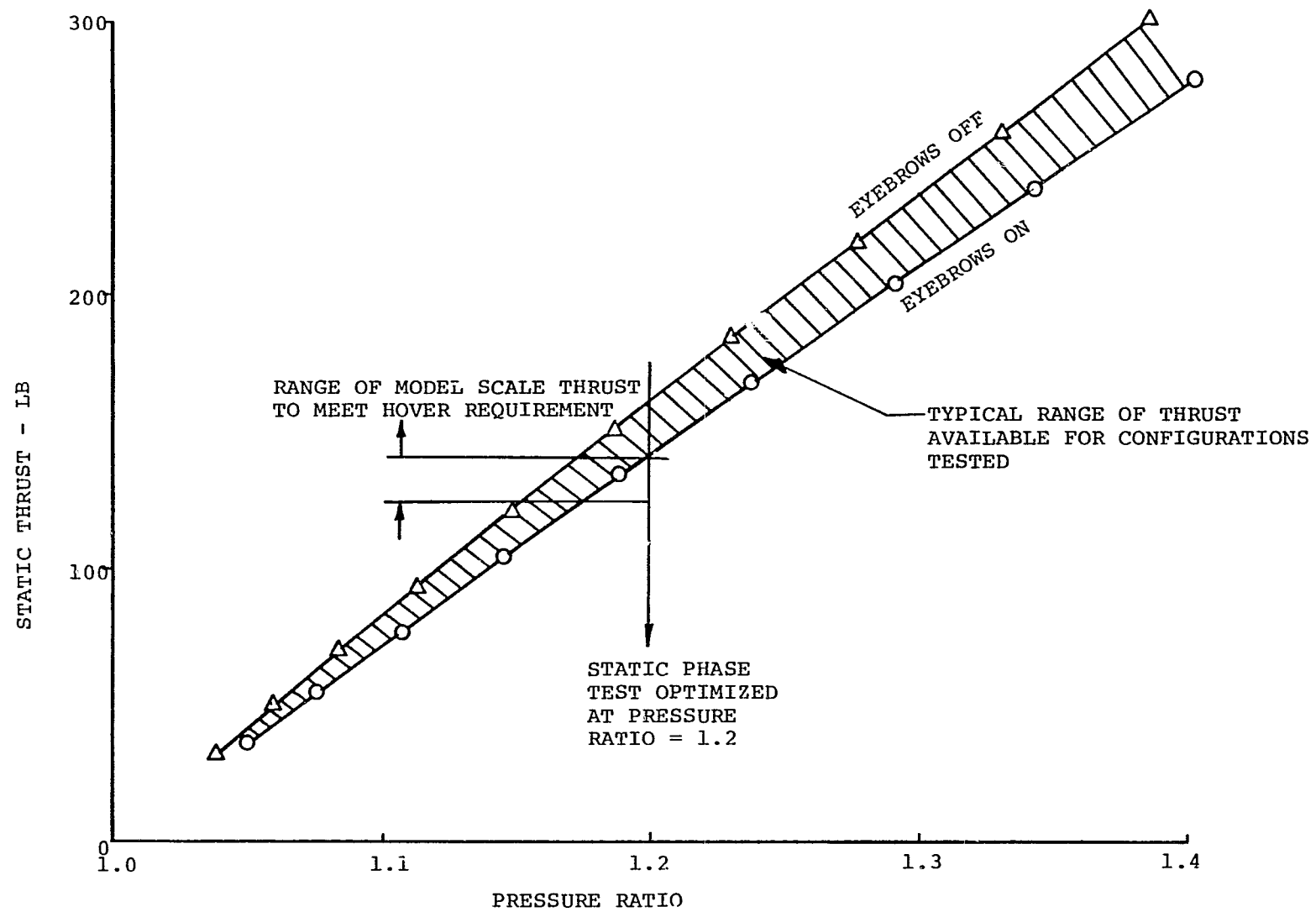


Figure 6.2-1. Hover Thrust Scaled to Model Size

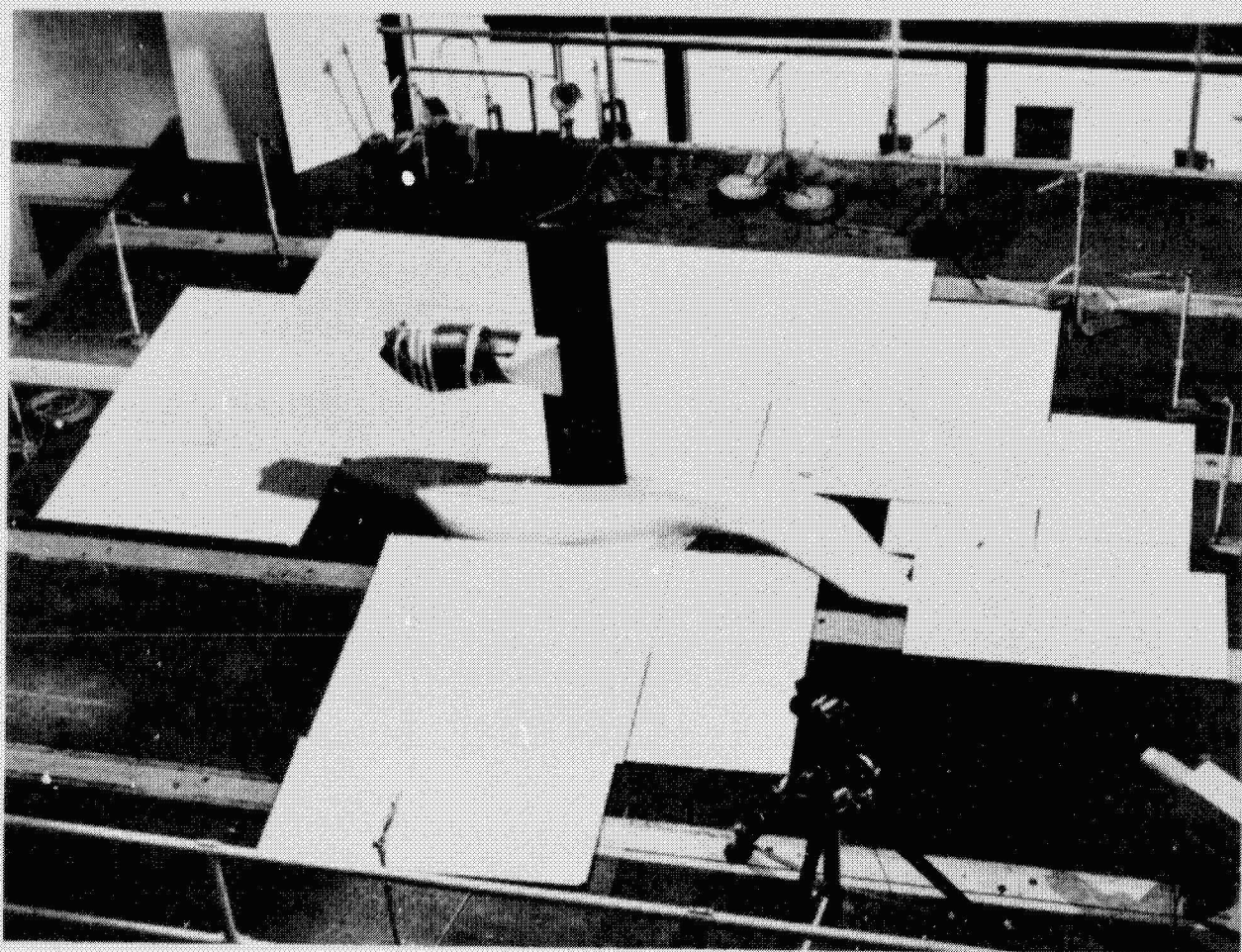
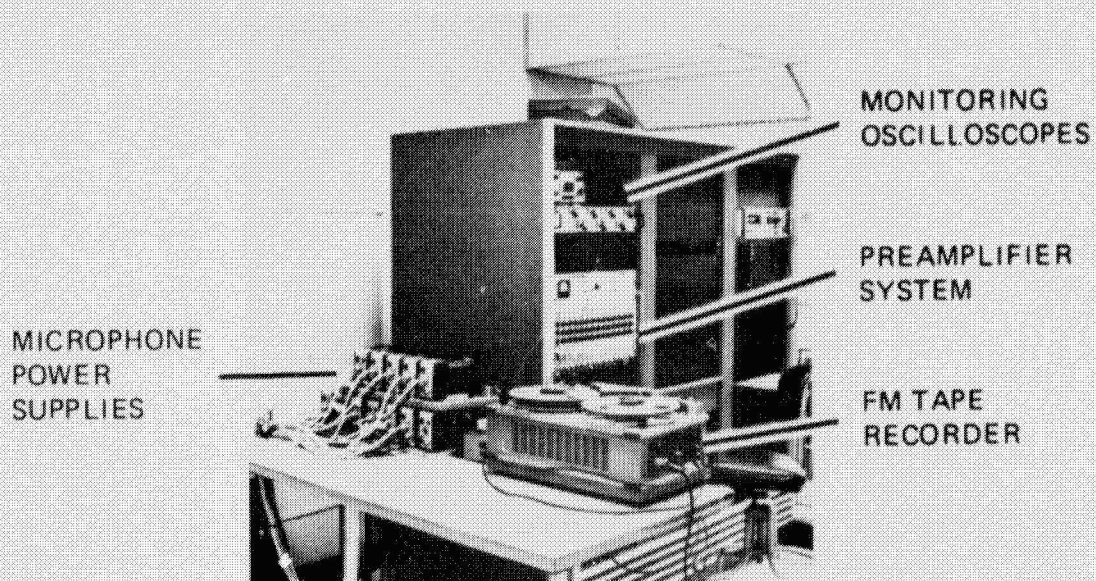


Figure 6.3—1. Installation of CSB Model and Microphones in Open Test Section of Wind Tunnel



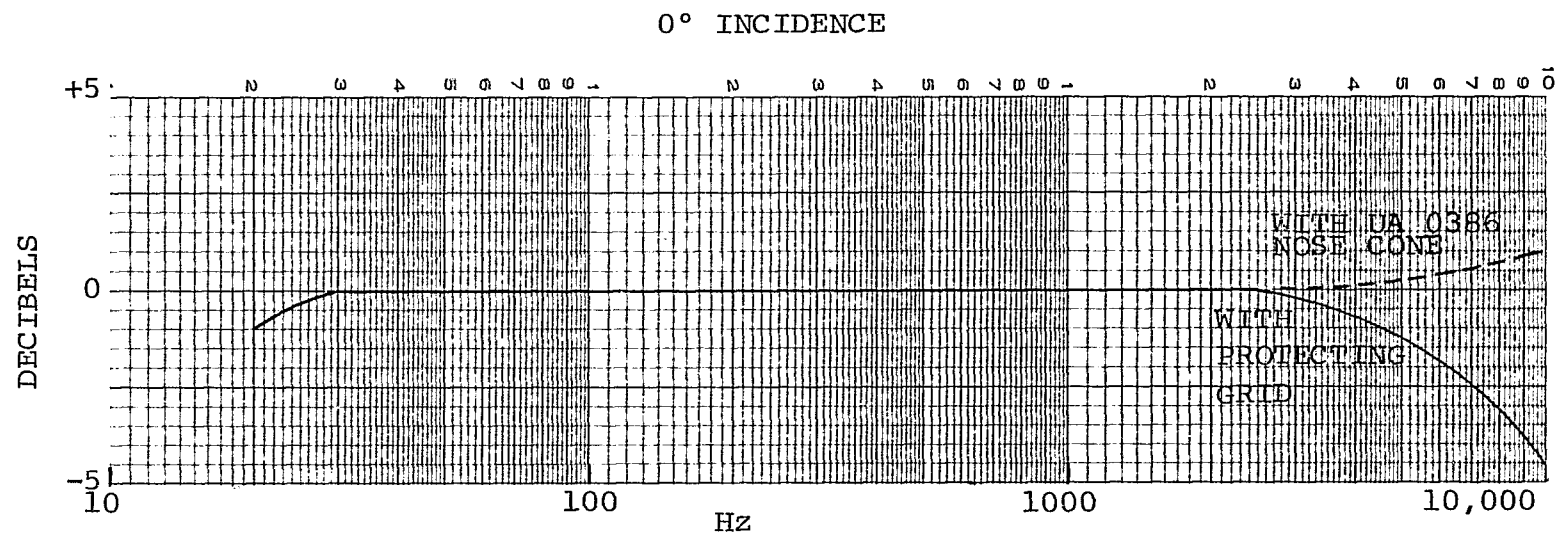
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Figure 6.3-2. Microphone Assembly



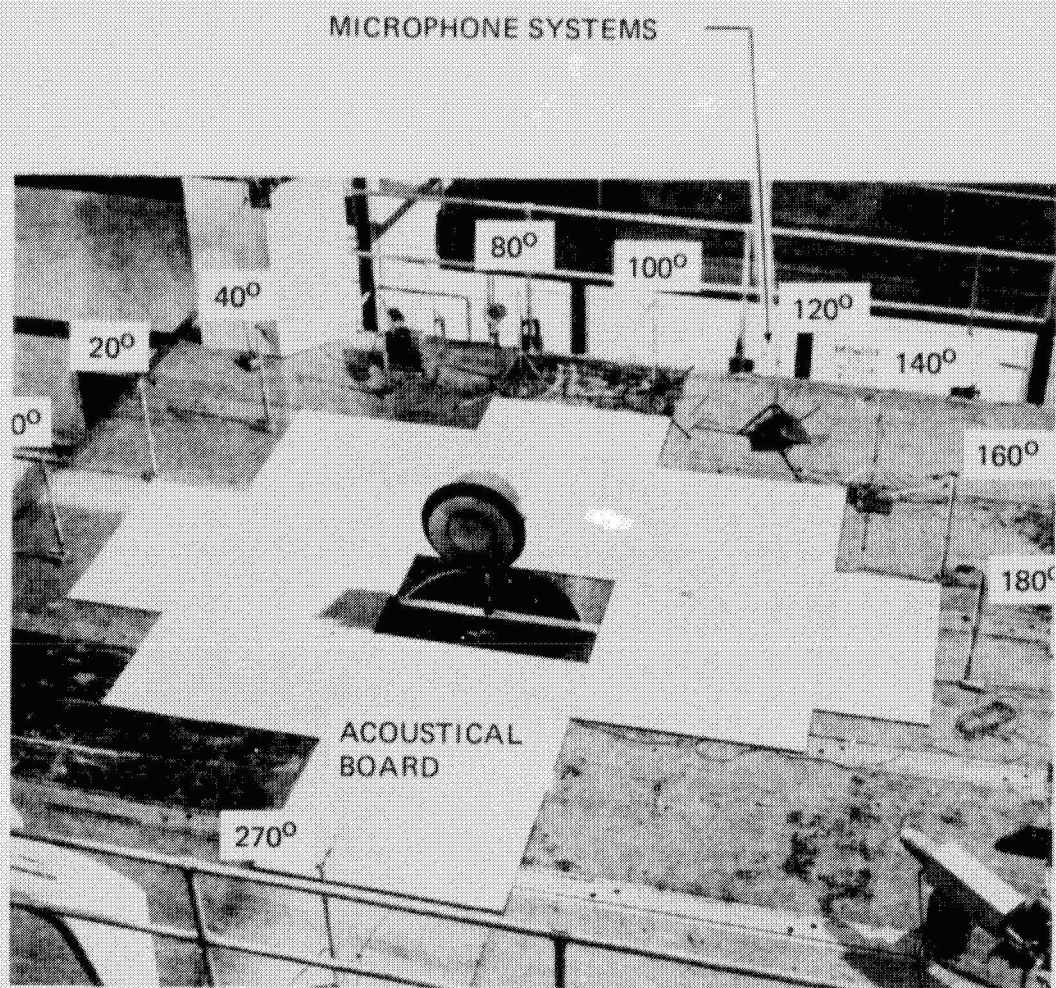
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Figure 6.3-3. Recording Instrumentation



TOTAL SYSTEM RESPONSE
 BRUEL & KJAER (B&K) TYPE 4133 + 2615 MICROPHONE
 BRUEL & KJAER (B&K) TYPE 2801 POWER SUPPLY
 BRUEL & KJAER (B&K) TYPE AO 0029 CABLE

Figure 6.3-4. Microphone-System Calibration Chart



189457

Figure 6.3-5. Installation of Speaker in Test Section during Acoustical Calibration

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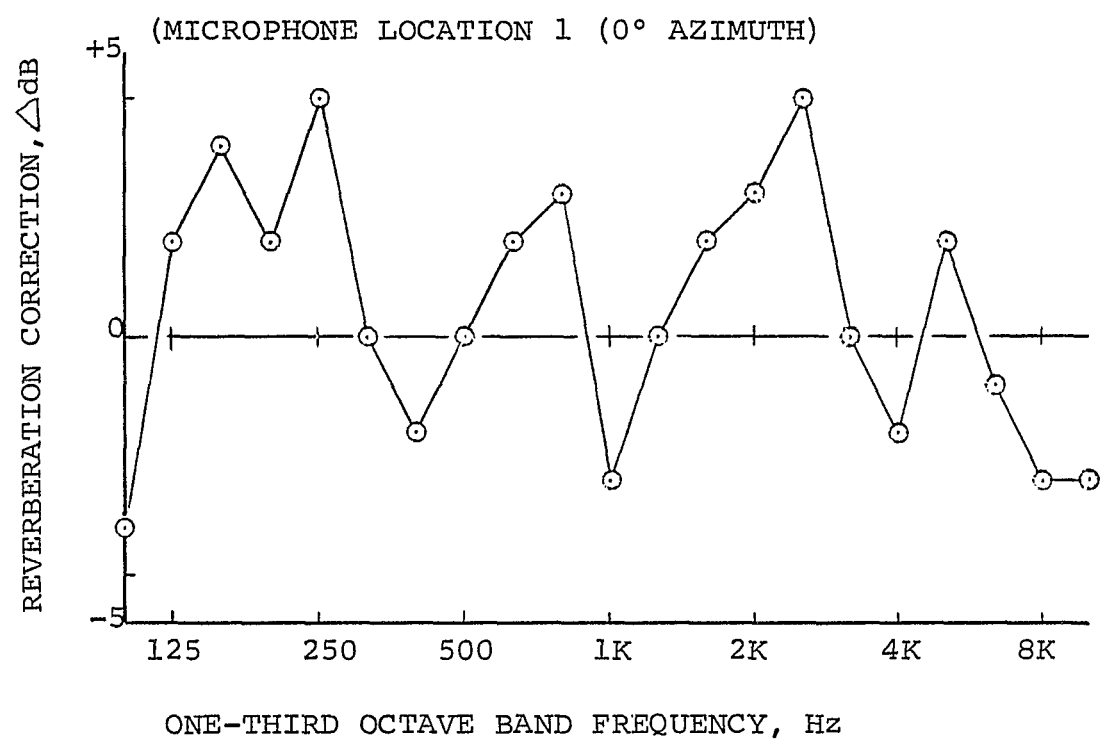


Figure 6.3-6. Wind-Tunnel Reverberation Correction for CSB Model

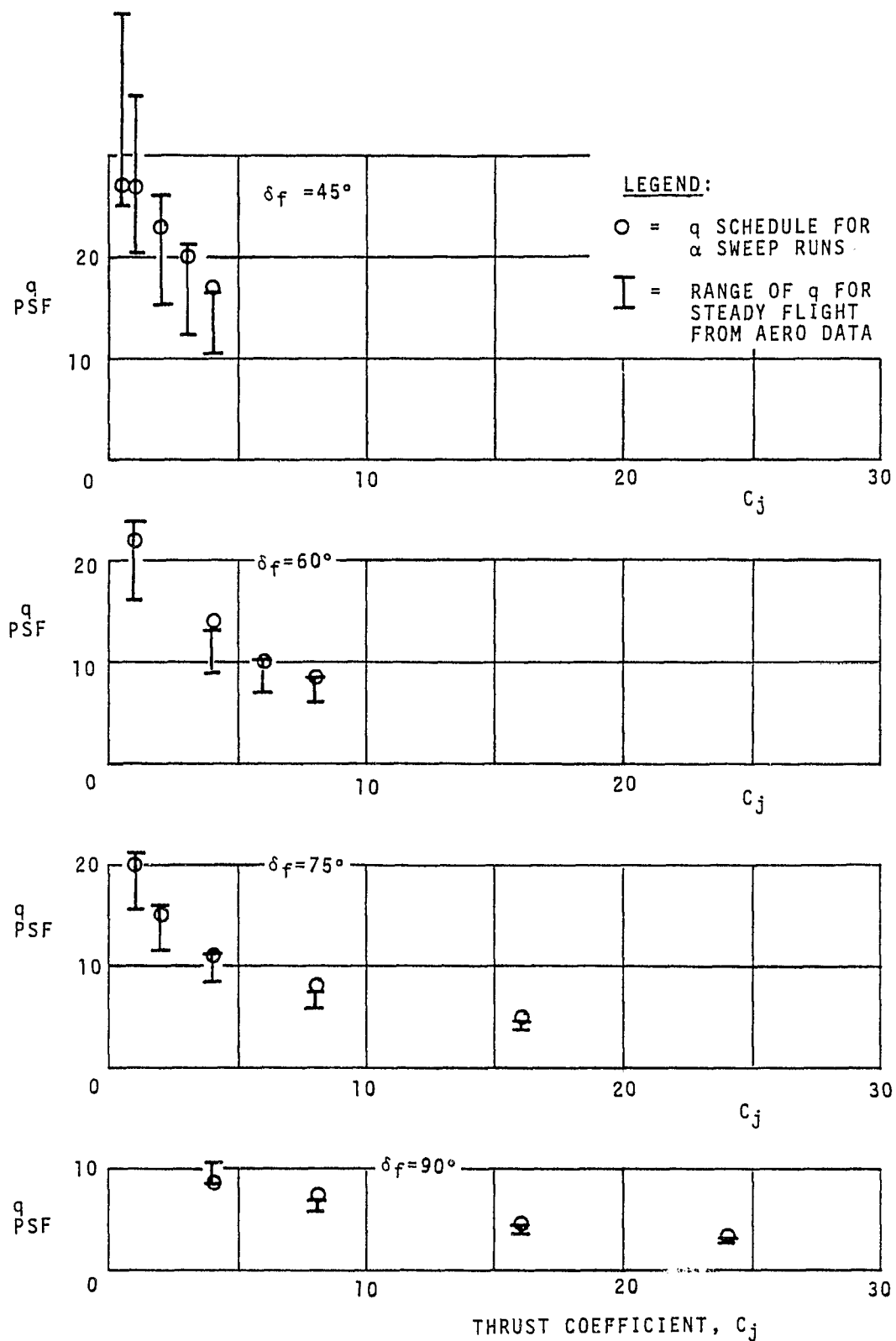


Figure 6.4-1. Basis of q Schedule for Transition-Phase Test

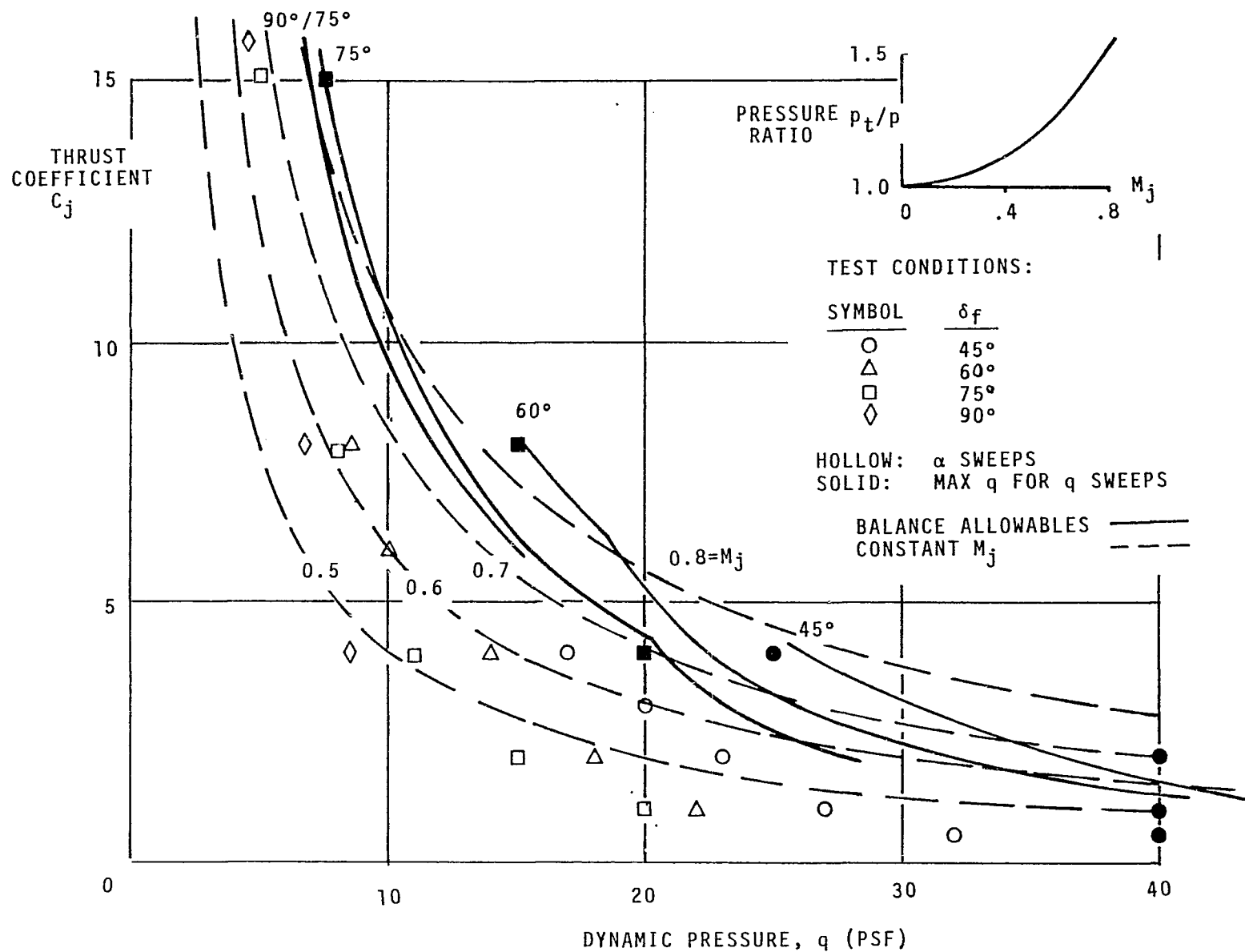


Figure 6.4-2. Summary of Transition Test Conditions

7.0 TEST RESULTS AND DISCUSSION

The primary objectives of this test on the combined-surface blowing model VX-119B-2 were outlined in the introduction and consisted of the following major items:

- a. Optimization of three triple-slotted, 90-degree flap configurations for maximum static-thrust recovery while developing turning angles of 85 degrees or greater.
- b. Effect of specific model-geometry modifications, such as nozzle eyebrows and wing fences, on static performance.
- c. Static-mode noise measurements as a function of flap angle and blowing configuration.
- d. Exploratory evaluation of performance capability in the transition-flight regime with the primary emphasis on the descent mode.

7.1 Static-Performance Testing Results

7.1.1 Static-performance comparison of three flap configurations. — The three triple-slotted flap designs that were optimized for maximum static-performance capability are schematically illustrated in Figures 3.2-2 through 3.2-4. In this investigation, the flap slot gaps, slot overlaps, slot nozzle entry and, to a lesser degree, flap segment angle were examined on flap configurations A and B with 89 degrees of deflection to establish the flap geometric characteristics required to achieve the best static lifting performance of each flap design. Figures 3.2-2 and 3.2-3 present the Flap A and B geometry, respectively, in the best performance configuration. Note that the large required gaps, as compared to the gap size for a conventional nonexternal-blown flap, give a staircase appearance to the optimized flap.

Since the testing of flap designs A and B resulted in similar slot-geometry characteristics for best performance, it was assumed that these slot characteristics should be applicable to the Flap C configuration. Consequently, Flap C was originally tested in a baseline configuration and then in a modified configuration to reflect Flap A and B test results. Some gap variations were evaluated with Flap C to check their sensitivity.

Figure 7.1-1 summarizes the static-performance level developed by each of the three flap configurations. All three flaps achieved similar levels of lifting capability and deflection angle, with flap designs B and C exhibiting a small lifting advantage over the Flap A design.

Whereas Figure 7.1-1 summarizes the static performance at a pressure ratio of 1.2, Figure 7.1-2 illustrates the variation of both thrust recovery and deflection angle over a range of pressure ratios from 1.05 to 1.40. Both of these performance parameters can be observed to decrease at the higher pressure ratios.

One of the major differences between flap configurations A, B, and C is the circumferential location of the second slot. Flap A uses the most forward location and Flap B the most aft location. In the Flap C design, the second slot was located about halfway between the Flap A and B positions. If the improvement in Flap B and C in static performance over that of Flap A can be attributed to the more aft second slot location, the effect can be judged to be minor.

7.1.2 Flap B configuration optimization. — Figure 7.1-3 summarizes the Flap B optimization testing in terms of illustrating the incremental changes in thrust recovery and deflection angle that were produced by variations in model geometry, such as No. 2 gap size, No. 1 flap angle, etc. The final configuration developed a thrust recovery 0.058 higher than the baseline Flap B without a loss in turning angle at the noted pressure ratio of 1.2.

Included in Figure 7.1-3 is the effect due to adding eyebrows to the upper and lower nozzle exits. These eyebrows, sketched in Figure 3.1-2, consisted of a one-inch-plate extension with a built-in 15-degree-upward deflection angle attached to the lower exit plane and a 0.5-inch-plate extension with a built-in 10-degree-downward deflection angle attached to the upper exit plane. These modifications produced approximately a 0.01 increase in thrust recovery with the lower eyebrow and a loss in turning angle which was more than compensated for by the 2-degree larger turning angle when the upper eyebrow was added.

Note that one of the incremental changes in static performance was produced by orientation of the model in the wind tunnel. The model was originally tested with the fuselage perpendicular to the tunnel centerline and the deflected flaps pointing down the center of the wind tunnel. Partway through the testing it was determined that this test condition caused a recirculation of flow around the wind-tunnel circuit and resulted in a download on the wing. The extent of this recirculatory interference was investigated and confirmed as discussed in more detail in Section 7.1.2.3. Subsequent runs were made with the model aligned with the tunnel center line so that the jet flow was directed into the tunnel plenum.

7.1.2.1 Flap B slot gap and angle variations: An increase and decrease in the No. 1 slot gap produced the variation in thrust recovery and deflection angle shown in the left portion of Figure 7.1-4. Information shown in this plot was obtained by cross-plotting the data depicted in Figure 7.1-5. The right plot of Figure 7.1-4 is an additional cross-plot to illustrate the relative change in the two parameters with gap size. As a consequence of varying gap size by vertically displacing the entire flap assembly with spacer blocks, the overlap also varied but by a low factor, i.e., when the slot size was modified by 1-percent C, the overlap changed by only 0.2-percent C.

Figure 7.1-4 indicates that a gap of between 3 and 4-percent C is required to maximize thrust recovery; however, turning angle is maximized at the smallest gap tested. In selecting the proper slot gap, thrust recovery was chosen to be the predominant factor as long as a turning angle of 85 degrees or more could be achieved. This criterion was based on the assumption that the additional 5 degrees of turning necessary for hovering flight can be obtained with a 5-degree nose-up aircraft attitude. This is typical of current operational vertical-lift aircraft, including helicopters.

Also plotted on Figure 7.1-4 (from the basic data shown in Figure 7.1-6) is the effect of increasing the first flap angle from 39 to 43 degrees with the same gap setting. A significant decrease in thrust recovery is evident. In this investigation identical overlaps could not be maintained due to the aft movement of the first flap nose. Therefore, a run was performed with the flap nose modified to reduce the overlap by 1.4-percent C. No significant and favorable change in thrust recovery or turning angle can be ascertained from the data plotted in Figure 7.1-7.

Varying the second slot while maintaining constant first and third slot geometry produced the results depicted in Figure 7.1-8 for a pressure ratio of 1.2. Again, the information was derived by cross-plotting the data shown in Figure 7.1-9. Thrust recovery increased with gap size up to the maximum tested (4-percent C), and deflection angle peaked with a 3-percent gap. Since the second and third flaps were moved vertically to adjust the second gap, overlap did vary. To check the effect of changing the overlap from a positive to negative value as the gap was increased, the second flap nose was modified to decrease the negative overlap by 1.2-percent C. The net result was a loss in both thrust recovery and deflection angle as shown in Figure 7.1-9 (runs 26 and 27).

Third slot geometry was varied by moving the third flap both vertically and horizontally. As illustrated in Figure 7.1-10, the highest thrust recovery was achieved with the largest gap tested (3-percent C) regardless of the respective overlap. The data used to generate Figure 7.1-10 is plotted in Figure 7.1-11. It is interesting that the method of altering gap size (horizontal versus vertical movement of the third flap) had a similar effect on the static performance. Apparently, slot overlap was not a major factor.

Both the first and second flap gaps were separately closed completely to establish the respective importance of each slot. In these modifications, the slot closure was accomplished in a manner that resulted in a smooth transition to the adjacent slot on both upper and lower flap surfaces. As shown by the data plotted in Figure 7.1-12, closing the first slot, for larger pressures, did not reduce the thrust recovery by a large amount and also did not result in a large decrease in deflection angle. Closure of the second slot had a greater effect in that the decrease in both thrust recovery and deflection angle was greater. Since these runs were performed prior to adjusting the slots for maximum thrust recovery, their actual influence on static performance could have been found to be larger.

Early in the static testing, comparative testing was conducted to investigate the amount of performance degradation associated with tufted flaps. Figure 7.1-13 presents the data. The possible decrease shown by this data established a ground rule whereby all static-performance data would be acquired with the blown-wing area free of tufts and all tufted-flow visualizations would be performed in separate runs.

7.1.2.2 Flap B cove modifications: To examine the aerodynamic characteristics of the slots and slot coves, flow-visualization runs were performed. Both China clay and tuft runs indicated a large amount of spanwise flow in the first slot cove. This characteristic can be observed in both photos of Figure 7.1-14. In run 23, the wing cove was modified in an attempt to reduce the losses through the slot; however, as shown in Figure 7.1-15, this was not

realized at the reference pressure ratio of 1.2. The subsequent degradation in static performance could have resulted from an increase in the total angular-flow change through the cove S-curve. Later in the test program, a more modest modification to the first cove again did not provide an improvement at a pressure ratio of 1.2. See Figure 7.1-16 for the comparison. This result could have been influenced by the lower and upper nozzle eyebrows added for these runs.

Another visual examination with tufts mounted on stalks in the wing cove but 0.25 inch above the model surface (run 33) plus a probe with a tufted wand revealed that a separation bubble existed in the cove. It was largely this observation that led to the addition of lower nozzle eyebrows, the testing of which is discussed in a following section.

A further attempt at lessening the severity of the first cove S-curve, which is a function of the basic airfoil-section thickness, was made by moving the entire flap assembly aft by 3.3-percent C. This movement increased the gap size by 1.1-percent chord. Figure 7.1-17 presents the comparative data which was acquired with both nozzle eyebrows installed plus the refaired first cove. Some improvement in thrust recovery occurred at pressure ratios below 1.25, whereas the variation in deflection angle exhibited the opposite trend. This thrust-recovery increase merely balanced out the loss incurred by the first cove modification in Figure 7.1-16 for the both-eyebrows-on case. With the flap moved aft, lowering the entire flap assembly by an equivalent 1.2-percent gap produced a substantial loss in deflection angle.

The second slot cove on Flap B was also modified to further examine the relationship of slot entry to static performance. Comparative data in Figure 7.1-18 indicates a significant gain in thrust recovery with little change in turning angle.

Flow separation was also observed in the third slot cove via a China clay run. As a result, the lower-surface curvature of the second flap (which provides the third slot entry) was reduced. This change produced a small improvement in thrust recovery at 1.2 pressure ratio but at the same time decreased deflection angle. See Figure 7.1-19 for the data.

7.1.2.3 Effect of model orientation: During the static phase of testing, it was discovered that the orientation of the model had an influence on the measured static performance. The pertinent data describing this problem is displayed in Figure 7.1-20. When the model was set at zero angle of attack, the jet efflux passing over the 90-degree flaps was discharged across the static-test chamber, which had been enlarged from a 20-foot-wide test section to a 67-foot-diameter plenum by removal of the 29-foot-long test-section walls. Pitching the model to a -90 -degree attitude directed the efflux down the test-section diffuser and thus provided a potential power source for driving the tunnel at a low but meaningful q .

The comparisons in Figure 7.1-20 show a significant effect of orientation on thrust recovery (about 1 percent) at 1.2 pressure ratio and a lesser but opposite impact on deflection angle. This problem was investigated visually through placement of a large tuft grid upstream of the model. Observations of the tuft activity at a representative nozzle mass flow of 12 lb/sec confirmed the supposition that the pod efflux could induce flow around the center of the tunnel circuit and create some erroneous normal force when the model was oriented at a

—90-degree angle of attack. Pressure measurements taken just upstream of the model and thus normal to the wing surface with the latter orientation indicated that a recirculation velocity of 13.2 fps (0.21 q) was created at a nozzle pressure ratio of 1.26.

A forward-flight run with flaps set at 90 degrees and a pitch angle of —90 degrees was performed to measure the equivalent flat-plate drag area. The data presented in Figure 7.1-21 represents a drag of 6 square feet at low q values, which in turn represents 1.3 pounds of normal force during static testing at the noted 1.26 pressure ratio. This 1.3-pound force from recirculation would decrease the thrust-recovery value from 0.890 to 0.883, a difference that matches the run 44 and 45 comparison in Figure 7.1-20.

7.1.2.4 Nozzle eyebrow effectiveness with Flap B: Of the various model modifications tested, such as nozzle eyebrows, wing fences, and flow directors, only the nozzle eyebrows produced an improvement in static-thrust recovery. Figure 7.1-20, which illustrated the effect of model orientation on static performance, also depicts the increase in thrust recovery that can be attained via the addition of lower nozzle eyebrows. With this modification, some decrease in deflection angle occurred. Even though these eyebrows improved the thrust recovery, flow-visualization runs made with China clay (run 73) and tufts (run 74) indicated only a minor decrease, if any, in the size of the first cove separation bubble previously observed during eyebrow-off runs.

The Figure 7.1-22 data provides another set of curves that shows the effect of lower nozzle eyebrows and also the change due to the further addition of upper eyebrows. Adding upper eyebrows increased the thrust recovery but by a smaller increment than the lower eyebrows. Deflection angle improved by over 2 degrees at a nozzle pressure ratio of 1.2. The net effect at this pressure ratio with both eyebrows installed is a 0.015 increment in thrust recovery and a 2-degree-larger deflection angle.

7.1.2.5 Wing fence and flow director evaluation: Two additional configuration modifications (lower-surface fences and upper-surface flow directors) were separately evaluated during the Flap B design testing in an attempt to improve the overall static performance. The wing fences were attached directly to the flap brackets on the lower surface and extended in a straight line from the entrance of the first slot to the trailing edge of the third flap segment, thus creating a trough into which the flow from the lower nozzle was directed. Comparative data plotted in Figure 7.1-23 shows a substantial loss in thrust recovery and a positive change in deflection angle at a pressure ratio of 1.2 with the fences installed. Lower-surface tuft activity that was observed both with and without the fences indicated substantial spanwise flow in the blown-flap area adjacent to the flap tracks. With the fences installed, the tuft behavior near the fences became erratic and the data, as shown in Figure 7.1-23, had considerable scatter. This change in flow characteristics could have resulted in some thrust-recovery loss even without the fences, since the model flap tracks projected below the flap surfaces.

The objective of the upper-surface flow directors, which were curved surfaces extending aft from the sides of the upper nozzle exit, was to aid the lateral spreading of the upper-nozzle

air. Figure 7.1-24 shows that some improvement in deflection angle did occur; however, this was not accompanied by an increase in thrust recovery.

7.1.2.6 Data repeatability: Data repeatability was continuously checked during the test by acquiring the usual repeat data points and by obtaining data during an incremental decrease in pressure ratio as well as during the incremental increase in pressure ratio. A comparative example of repeat data runs is presented in Figure 7.1-25. Repeatability in both thrust recovery and deflection angle can be noted to be excellent for this example.

Considerable data scatter, primarily at the lowest pressure ratios, was evident, however, with some of the configurations tested. This condition appeared to be configuration-dependent since other configurations did not exhibit this characteristic.

7.1.3 Flap A configuration optimization. — The optimization testing performed on the conventional triple-slotted Flap A design is summarized in Figure 7.1-26 for the pressure ratio of 1.2. Figure 7.1-26, which is similar to Figure 7.1-3 for the Flap B design, illustrates the combined change in thrust recovery and deflection angle for individual changes in gap geometry plus the benefit from adding an upper nozzle eyebrow. The eyebrows were identical to those evaluated during the Flap B testing. During all the Flap A runs the model pitch angle was maintained at zero angle of attack to minimize potential recirculation effects.

The performance capability generated by the final Flap A configuration approximated the level achieved by Flap B and was increased by 5.0% in thrust recovery and 3.2 degrees of deflection angle over the values measured with the baseline Flap A configuration. The best configuration of Flap A displayed considerable scatter in repeat runs 88 and 89. The lower values from run 89 are plotted in Figure 7.1-26. As in the Flap B case, the eyebrows produced a substantial portion of the increment.

7.1.3.1 Flap A geometry variations: Individual variations in the three Flap A slots produced the results depicted in Figures 7.1-27 through 7.1-29, the left plots of which are cross-plots of the basic data presented in Figures 7.1-30 through 7.1-32 at the pressure ratio of 1.2. Again, the right plots (Figures 7.1-27 through 7.1-29) are further cross-plots to depict the change in thrust recovery and deflection angle with gap size. The gaps were varied in the same manner in which they were varied during Flap B testing; that is, the entire flap assembly was vertically translated to modify slot No. 1, both the second and third flaps were vertically translated to modify slot No. 2, and slot No. 3 was varied by moving the third flap segment vertically and horizontally.

As in the Flap B testing, Figures 7.1-27 through 7.1-29 show that gap sizes of a 3-percent C magnitude or larger are required to maximize thrust recovery. Note that the performance variation due to changes in the No. 2 slot was the same with either of two different No. 1 slot gap sizes, indicating some independence of slot optimization.

Following the initial exploratory test, a question was raised as to whether the foreflap of the Flap A design was set at too shallow an angle for the proper No. 2 slot entry conditions. Data in

Figure 7.1-33 indicates otherwise in that a 9-degree increase in foreflap angle decreased both thrust recovery and deflection angle.

The slot coves were not modified during Flap A testing so that the effect of entry shape could be specifically evaluated on Flap A static performance. Changes made to slot entry shape (such as the modifications to the first slot cove) in the Flap B investigation were assumed to be valid for the Flap A configuration. During the Flap B program, the heel of the main flap (second flap in the Flap A configuration) was removed and as a consequence the benefit accrued by the improvement to the third slot entry was present in all the Flap A runs.

7.1.3.2 Nozzle eyebrow effectiveness with Flap A: As in the Flap B evaluation, the addition of an upper nozzle eyebrow again increased the deflection angle by over 2 degrees at the reference pressure ratio of 1.2. See Figure 7.1-34.

This modification with Flap A also provided a significant increase in thrust recovery. The Flap A testing was performed with the lower nozzle eyebrow installed and, as a consequence, the improvement in static performance associated with its installation as ascertained in the Flap B investigation was inherent in the Flap A runs.

After the testing of each slot gap individually, the flap brackets were redrilled to establish a best Flap A configuration. The performance obtained with this configuration (plus eyebrows) is compared in Figure 7.1-35 to an earlier Flap A run with both eyebrows installed. This figure includes a repeat run to evaluate data repeatability.

Subsequent to these runs the entire flap assembly was moved aft in an attempt to improve the flow through the first slot by making a reduction in the overall abruptness of the first slot S-curve. Figure 7.1-35 shows that this model change was unproductive in both thrust recovery and deflection angle. A similar result was noted in the Flap B investigations.

7.1.4 Flap C configuration static performance. — As previously stated, the primary purpose of the Flap C triple-slotted flap derivative was to establish a flap configuration that incorporated a location of the second slot around the flap-extension arc that was midway between the slot locations provided by flap configurations A and B. Flap C incorporated the same third flap segment used by Flaps A and B.

Since the slot-variation data acquired with flap configurations A and B exhibited a marked similarity, a decision was made not to duplicate the complete extent of this testing on the Flap C design. Thus, the best Flap C configuration was established based on data from pertinent Flap A and B testing as well as from Flap C runs. Figure 7.1-36 presents the static performance of the established best Flap C configuration with eyebrows installed and compares this data with the baseline Flap C. A substantial part of the illustrated performance improvement is attributable to the nozzle eyebrows.

7.1.4.1 Flap C geometry variations: Both the first and third slots were individually modified to the gap size deemed favorable from the Flap A and B data. The data plotted on Figures 7.1-37 and 7.1-38 does not display the increment in static-performance improvement for either thrust recovery or deflection angle that was attained in previous Flap A and B testing. A China clay flow-visualization run performed subsequent to the first slot gap increase and prior to the third slot gap increase again indicated the presence of a flow-separation bubble in the first slot cove and also flow separation in the third slot cove.

Based on these observations, the third slot cove was modified to eliminate the reflex curvature. This cove modification did provide an increase in static performance as shown in Figure 7.1-39; however, flow observations from a second China clay run still indicated separation in the third slot cove. The first slot cove was then modified and a possible small performance increase occurred. See Figure 7.1-39.

7.1.4.2 Nozzle eyebrow effectiveness with Flap C: A separate investigation of the lower nozzle eyebrow effectiveness was conducted with Flap C to verify the Flap B results. Figure 7.1-40 presents the data obtained from the Flap C runs performed both with and without the aforementioned first and third slot cove modifications. The improvement in thrust recovery can again be noted to be substantial.

7.1.5 Variation of static performance with flap angle. — In addition to the 89-degree flap angle, static performance was also measured with nominal flap settings of 75, 60, 45 and 104 degrees. See Figure 7.1-41 for the basic test data. The flap-angle designation conformed to the setting of the third segment. Flap segment angles and slot geometry for these Flap B configuration runs were not optimized by testing, but instead were established by using the 89-degree flap geometry to prorate the angles and flaps over a selected flap-extension schedule. The 104-degree setting was visualized as a configuration requirement for hovering in a tailwind. Since it would be advantageous for the third flap segment to provide the necessary control function in this hover condition, the 104-degree flap angle employed the first and second flap segment geometry of the 89-degree flap angle and the third flap was pivoted by a 15-degree increase. The specific geometry used for these settings is presented in Section 3.2.

The static performance obtained with the noted angular settings is depicted in Figure 7.1-42 along with the zero flap angle. Thrust recovery at 75, 60, and 45 degrees of flap angle approximated a 0.9 value, which was surprising in that it was anticipated that the thrust recovery would increase as the flap angle decreased. Two factors could have produced this trend, namely, that these flap settings were not optimized and second, pressure losses were present that did not decrease with a decrease in flap angle. A favorable finding was the small decrease in thrust recovery that occurred when the third flap angle was increased to a 104-degree deflection. As expected, the deflection angle achieved at flap angles less than 90 degrees approximated the nominal flap setting.

<u>SYM</u>	<u>RUN</u>	<u>FLAP DESIGN</u>
○	89	A
□	91	B
△	106	C

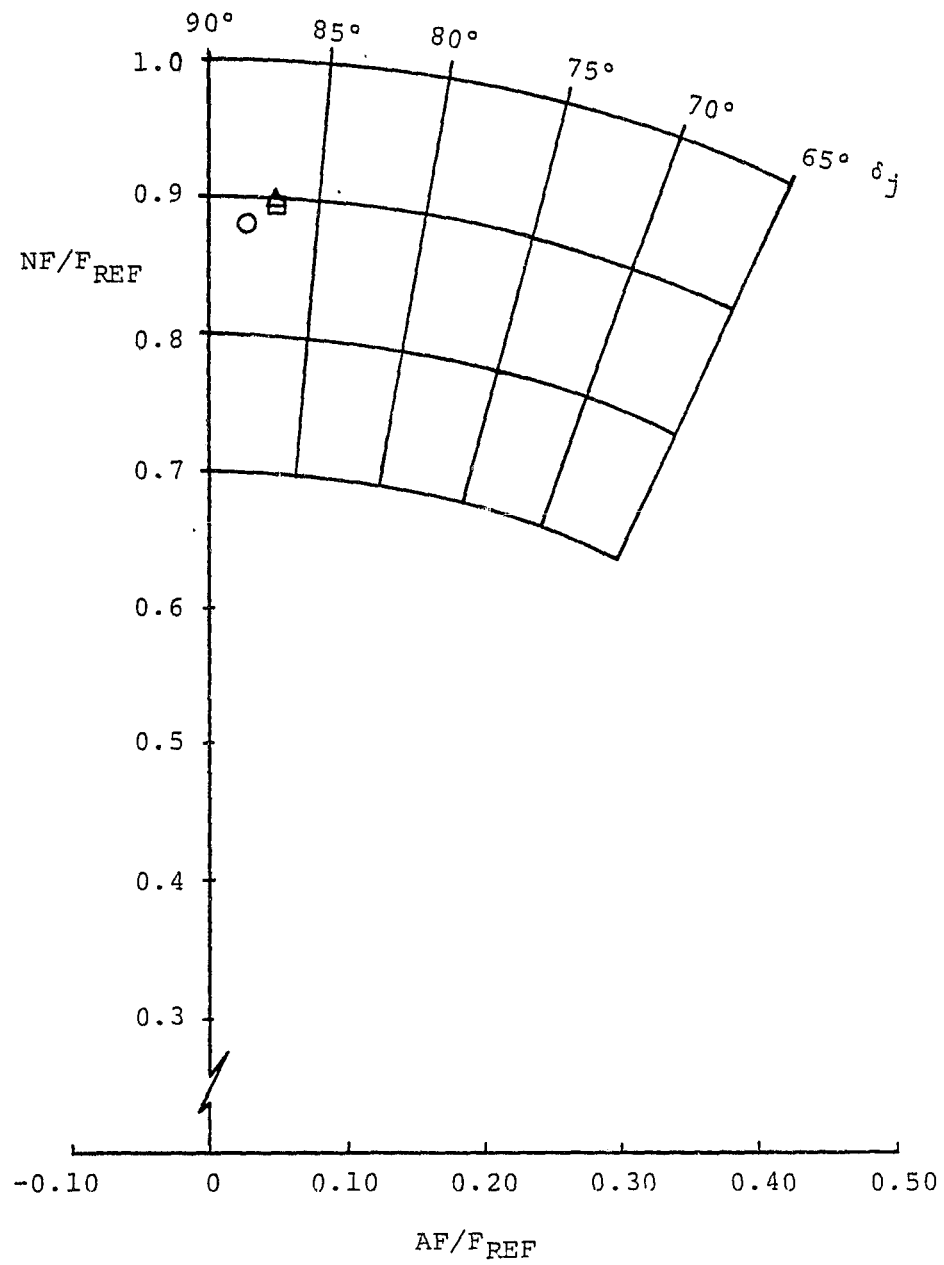


Figure 7.1-1. Summary of Flap Static Performance

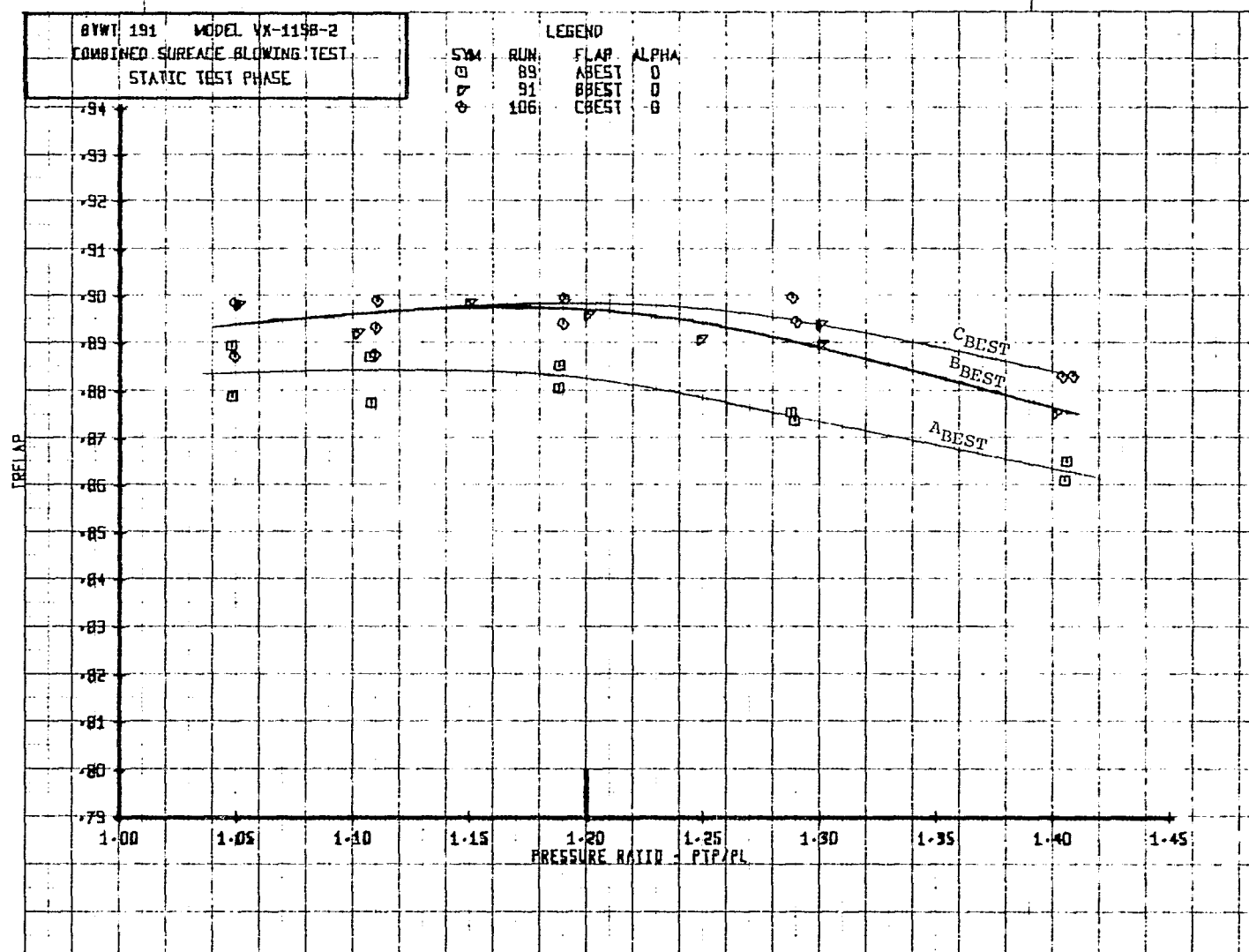


Figure 7.1-2. Performance Comparison of the Three Flap Designs:
a. Thrust Recovery

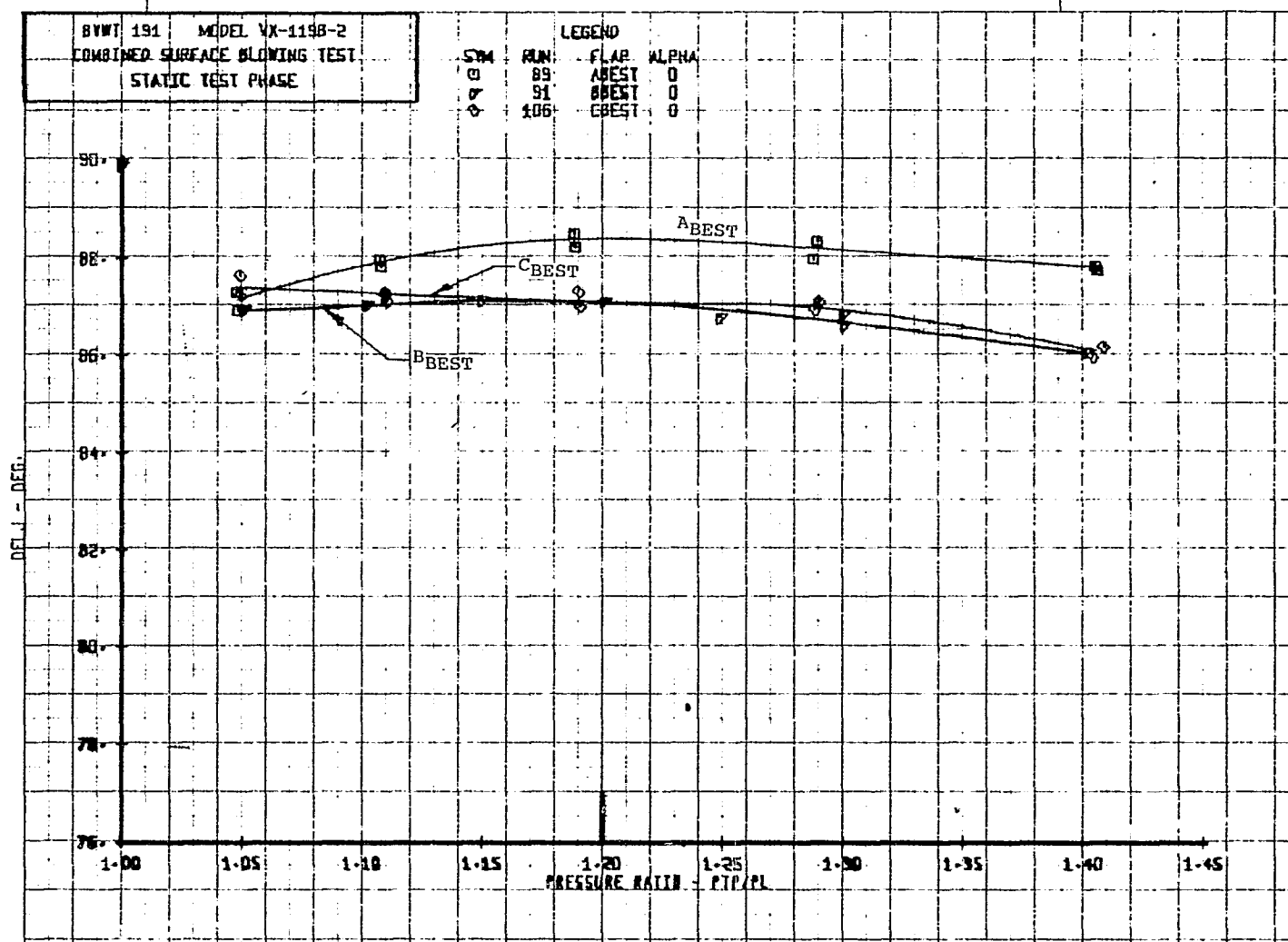


Figure 7.1-2. Performance Comparison of the Three Flap Designs:
b. Thrust-Deflection Angle

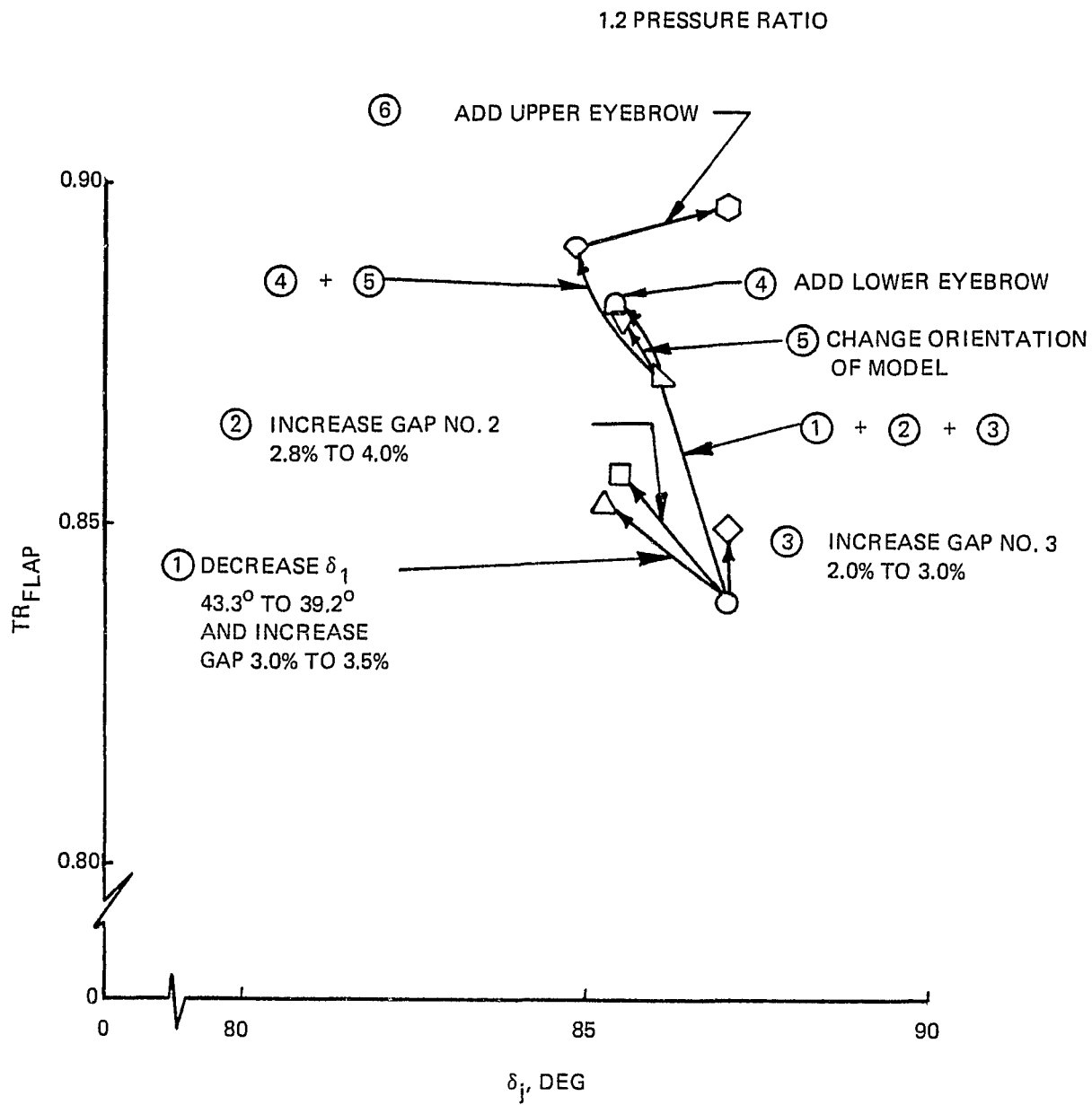


Figure 7.1-3. Improvement in Flap B Static Performance

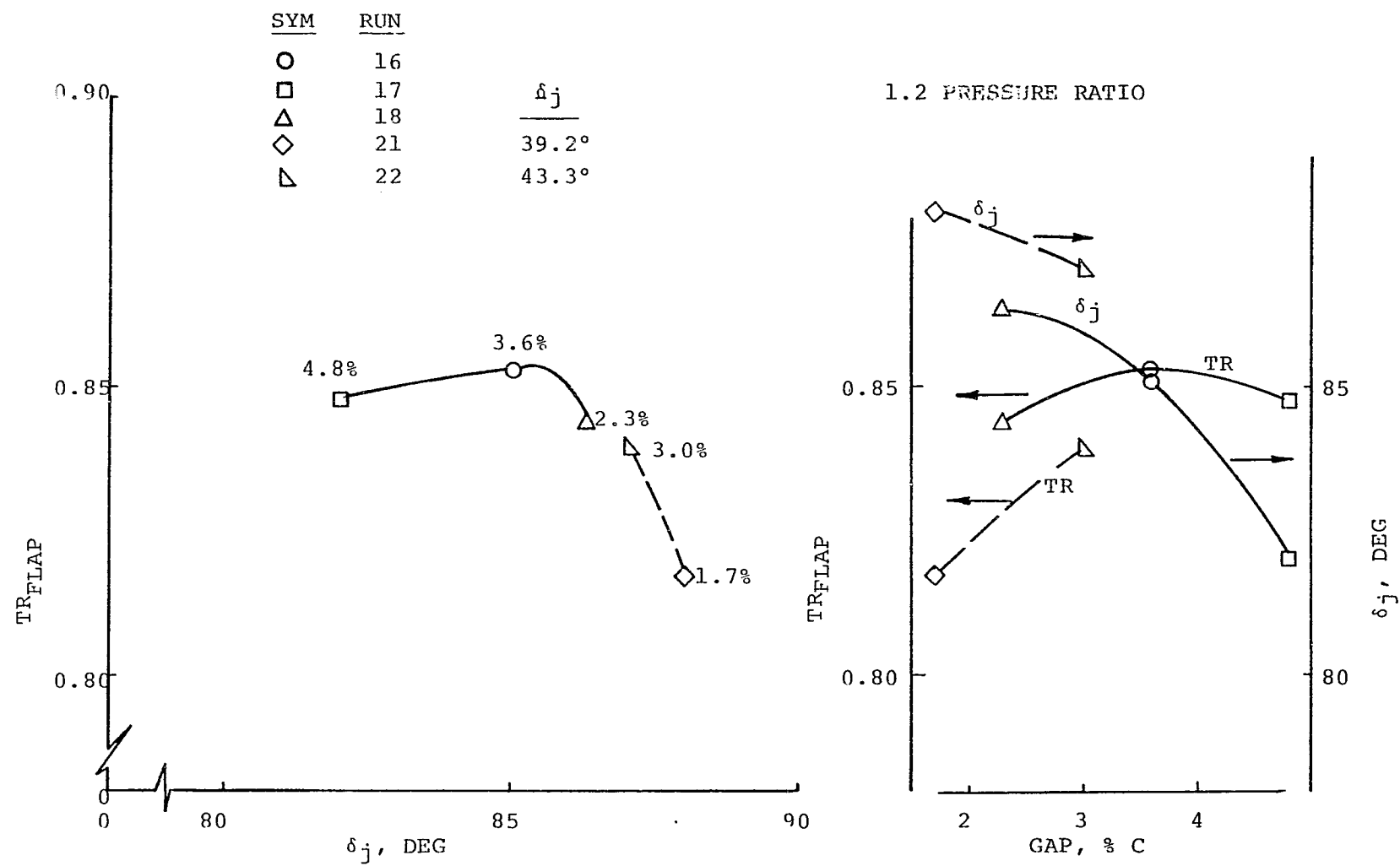


Figure 7.1-4. Flap B, Effect of Number 1 Gap and Flap Angle

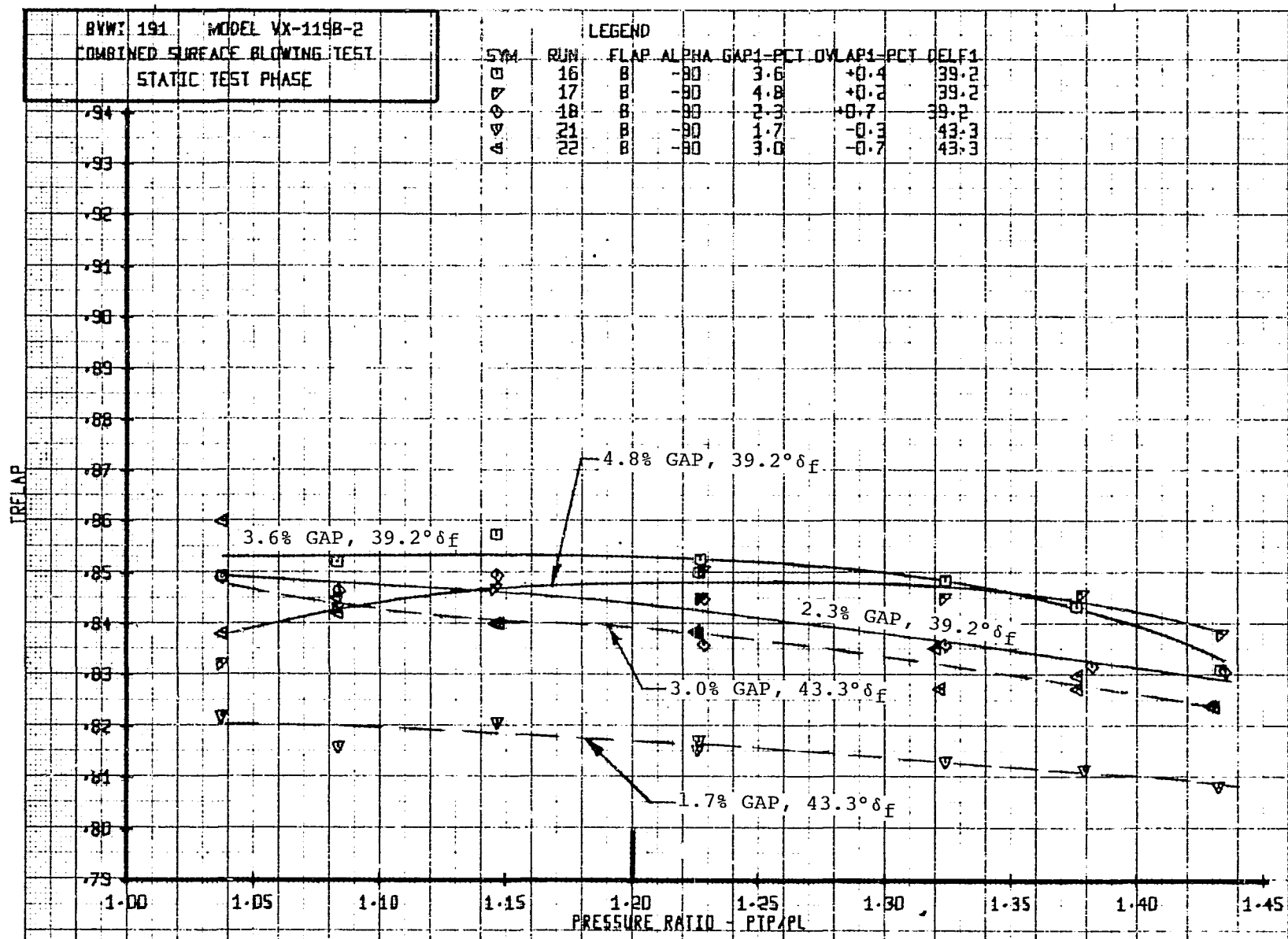


Figure 7.1-5. Flap B, First Slot Variation:

a. Thrust Recovery

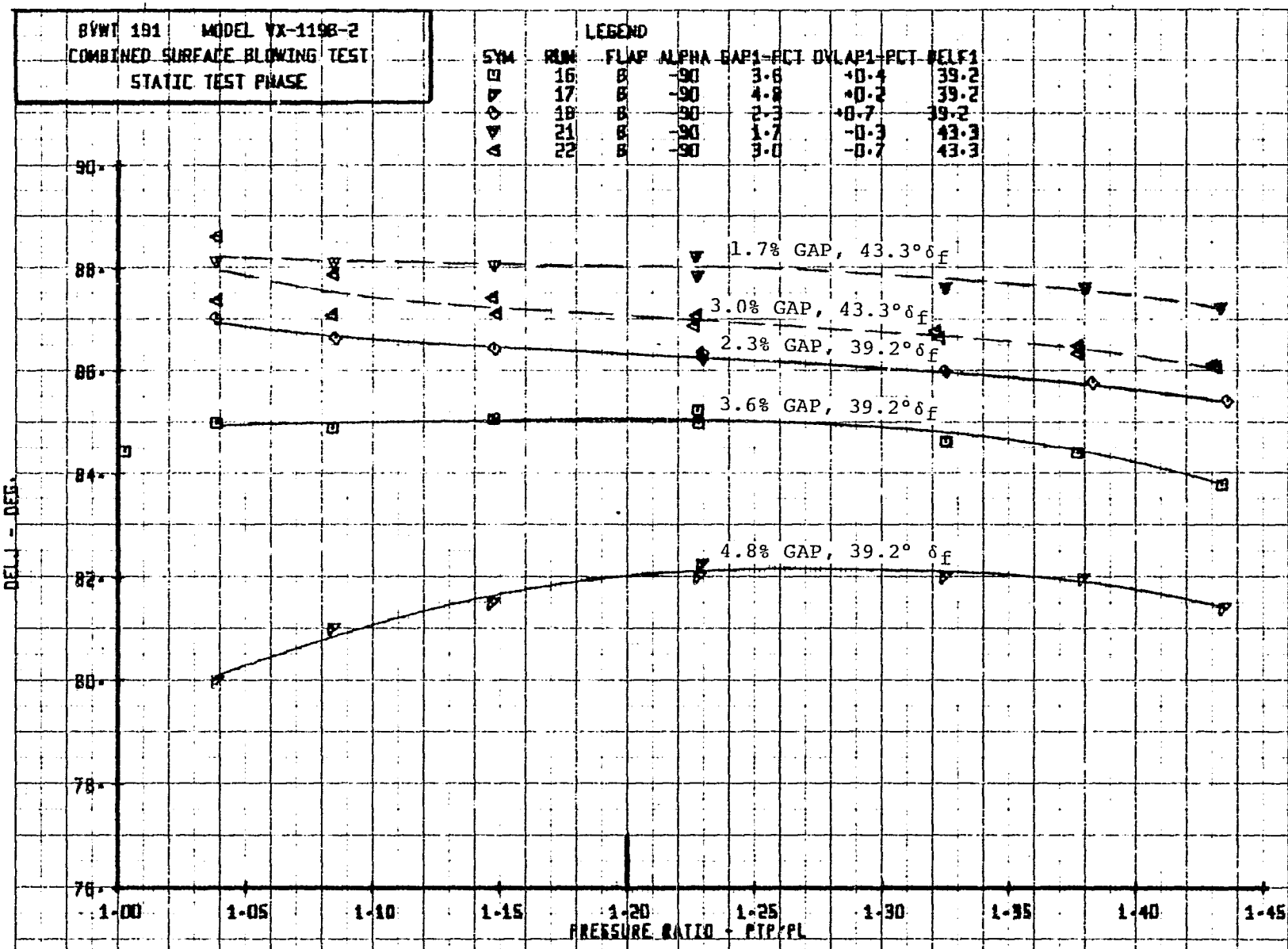


Figure 7.1-5. Flap B, First Slot Variation:
b. Thrust-Deflection Angle

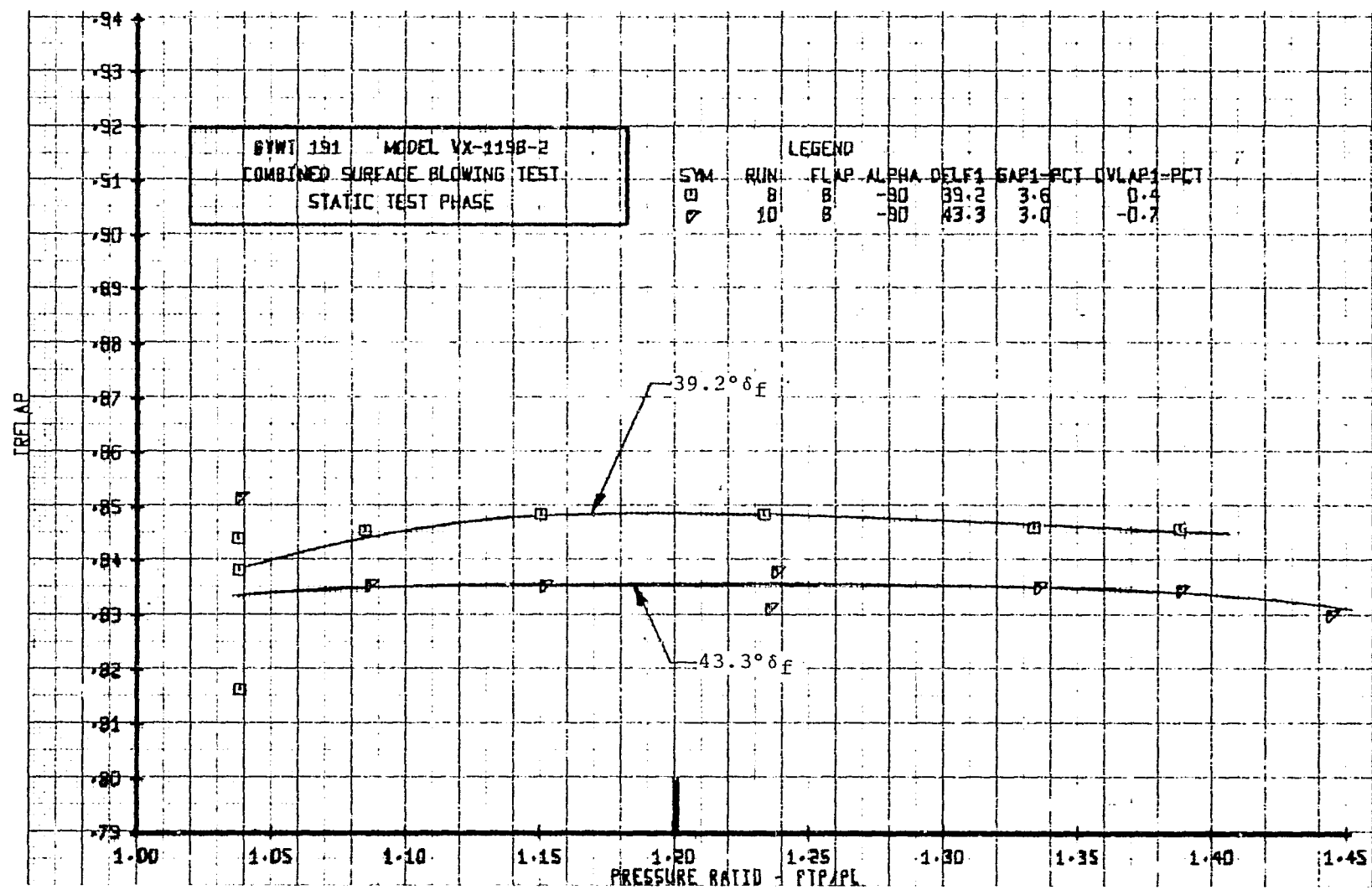


Figure 7.1-6. Flap B with Increased First Flap Angle:
a. Thrust Recovery

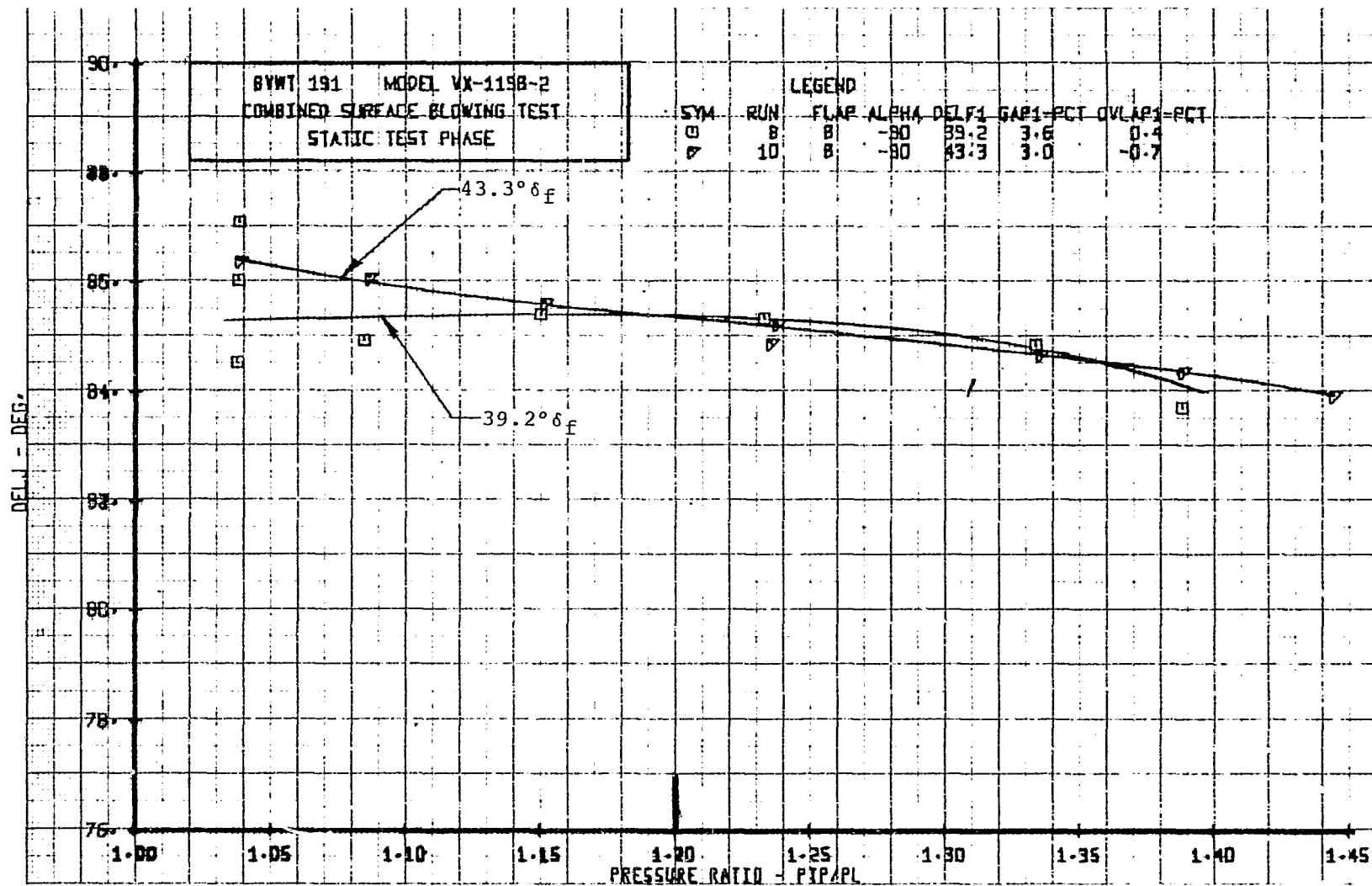


Figure 7.1-6. Flap B with Increased First Flap Angle:
b. Thrust-Deflection Angle

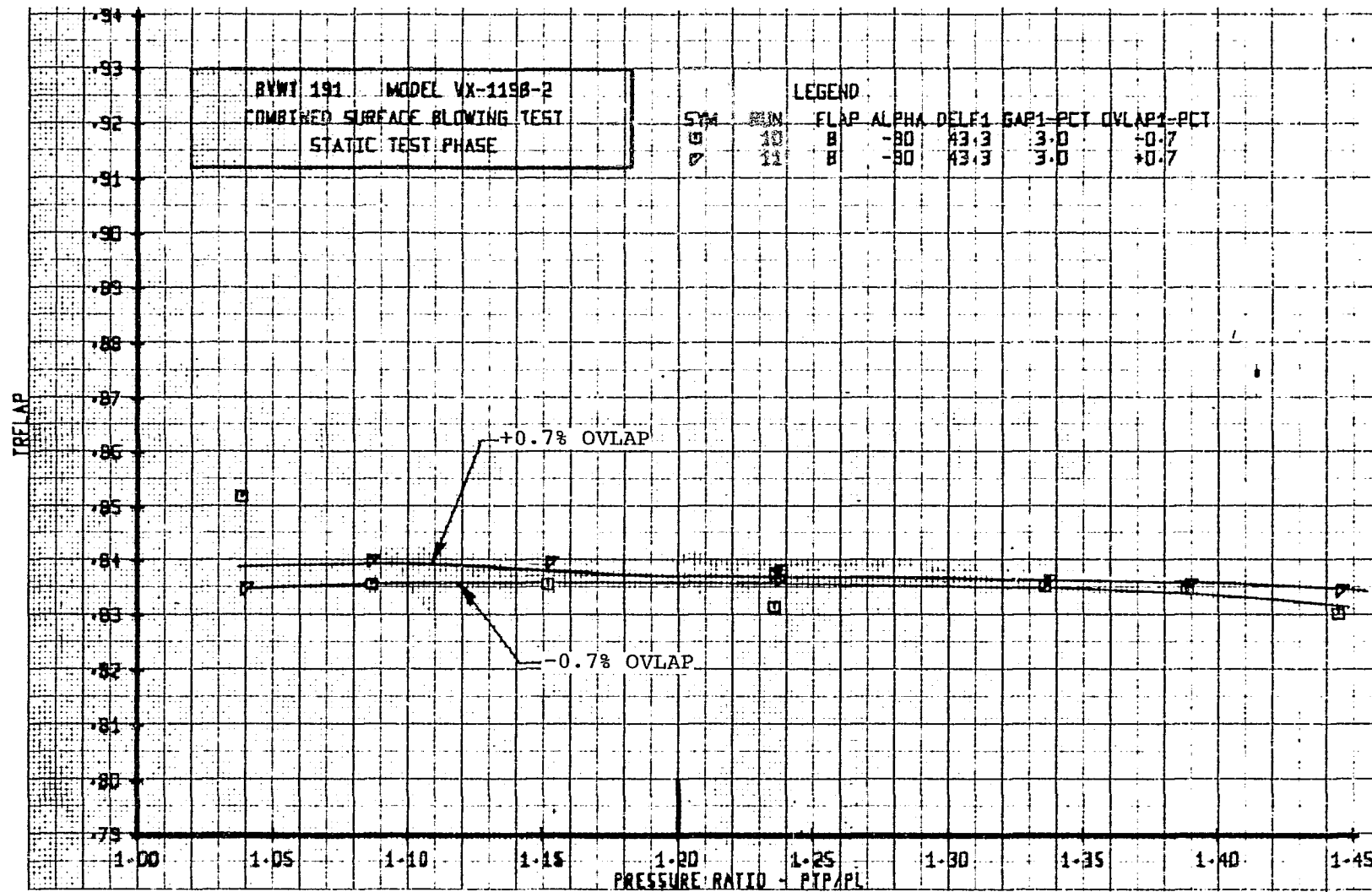


Figure 7.1-7. Flap B, First Flap Nose Modification (Overlap):
a. Thrust Recovery

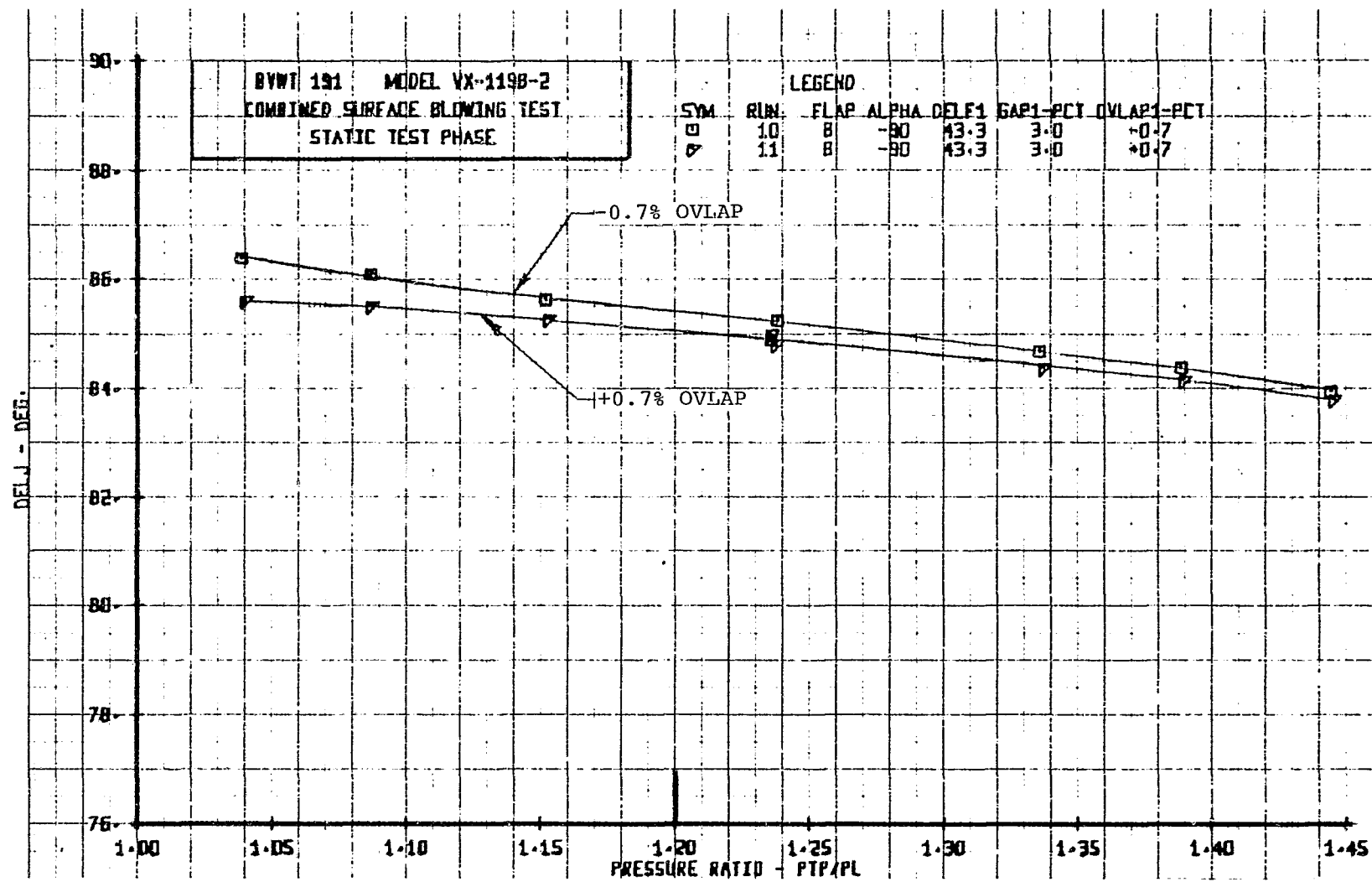
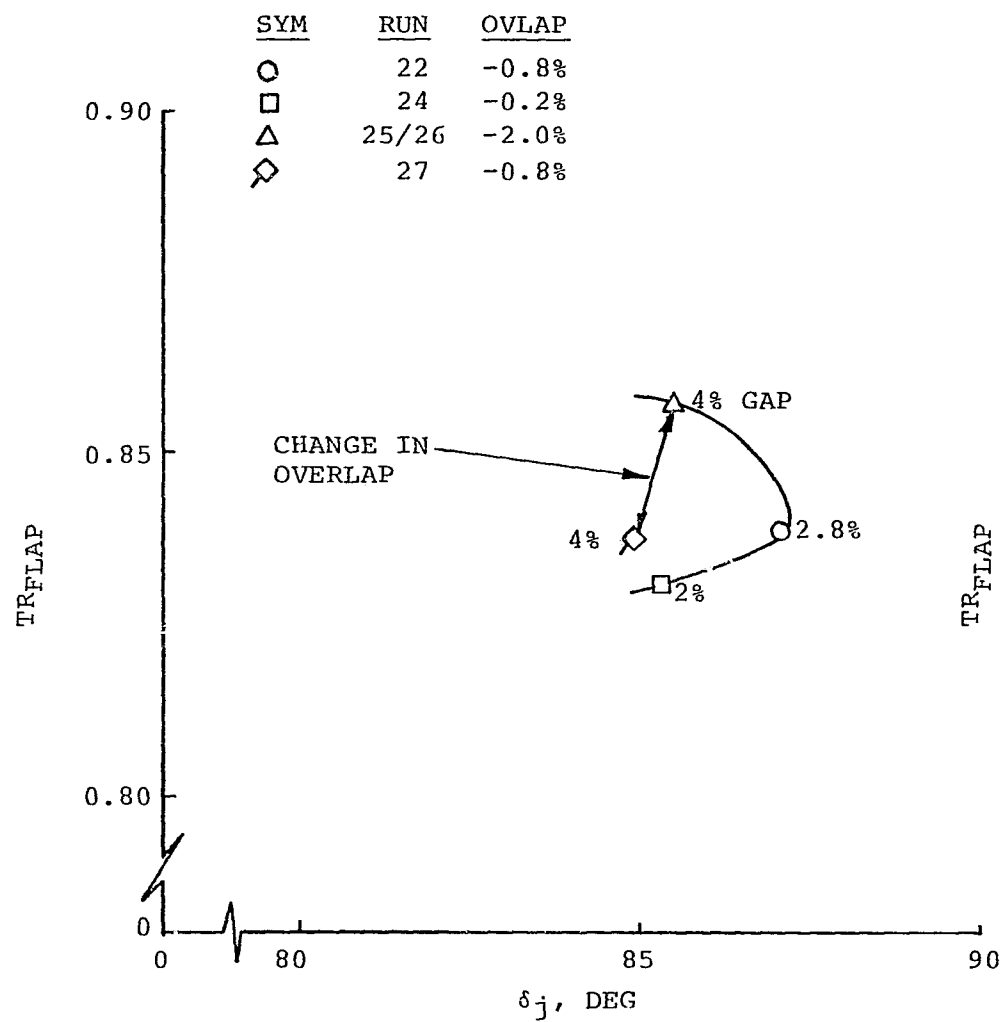


Figure 7.1-7. Flap B, First Flap Nose Modification (Overlap)

b. Thrust-Deflection Angle



1.2 PRESSURE RATIO

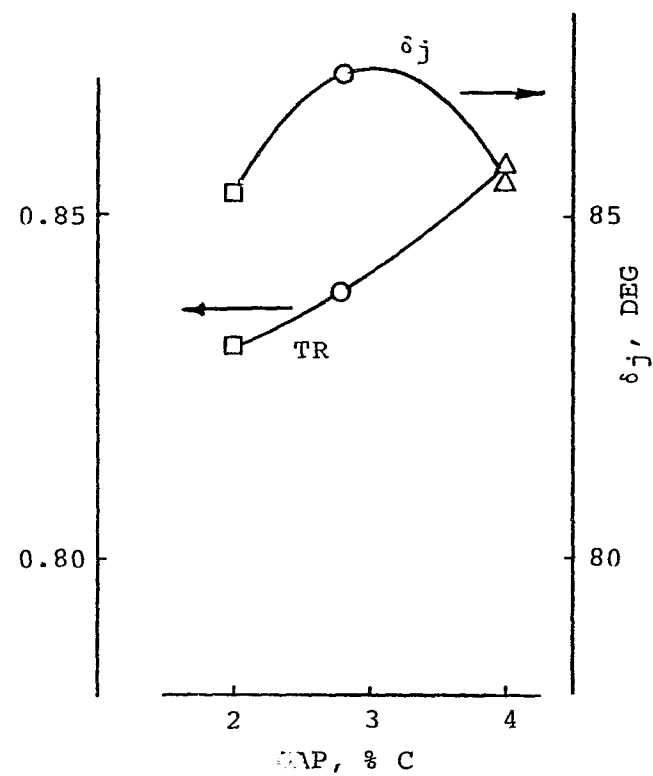


Figure 7.1-8. Flap B, Effect of Number 2 Gap

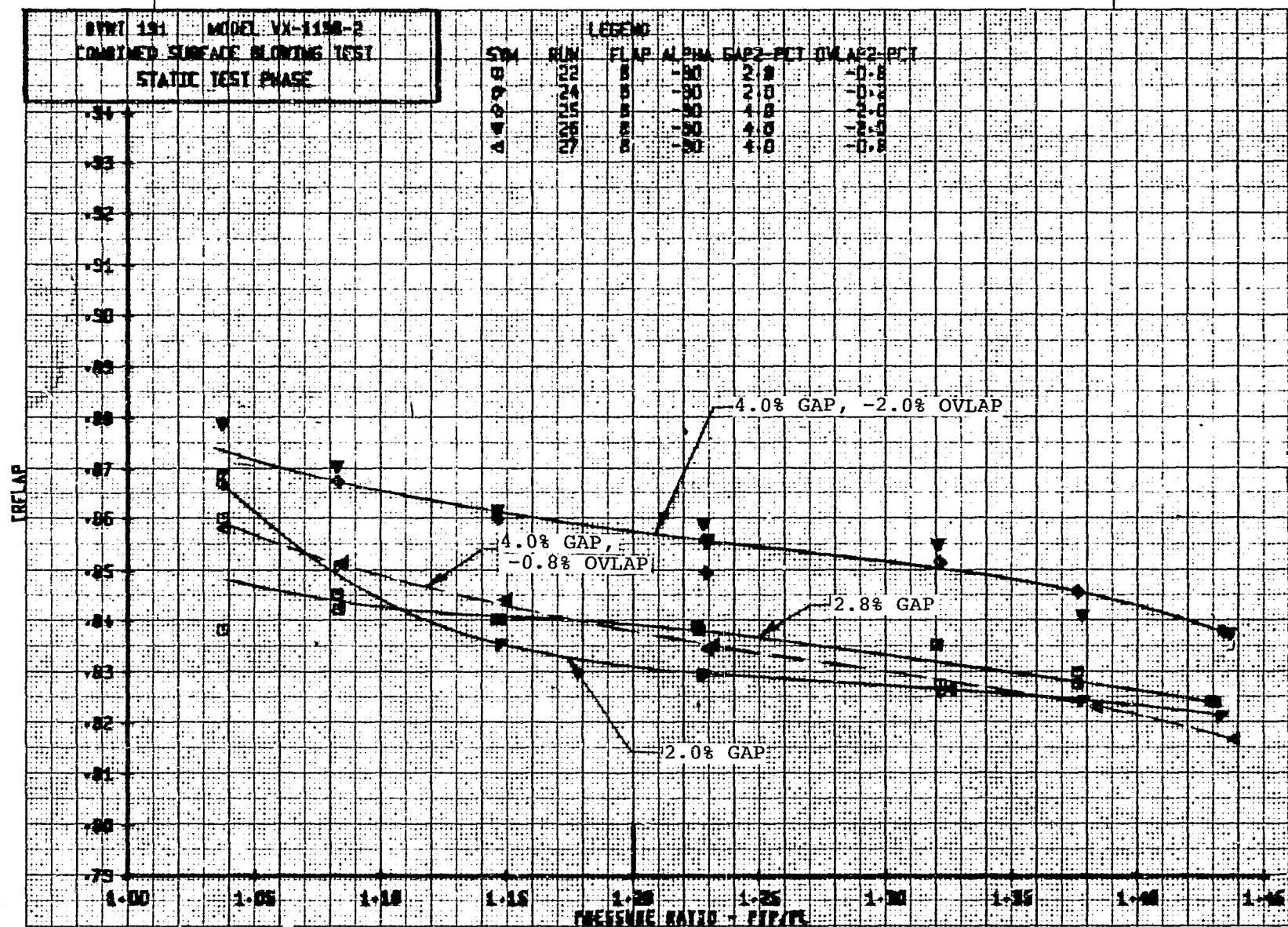


Figure 7.1-9. Flap B, Second Slot Variation
a. Thrust Recovery

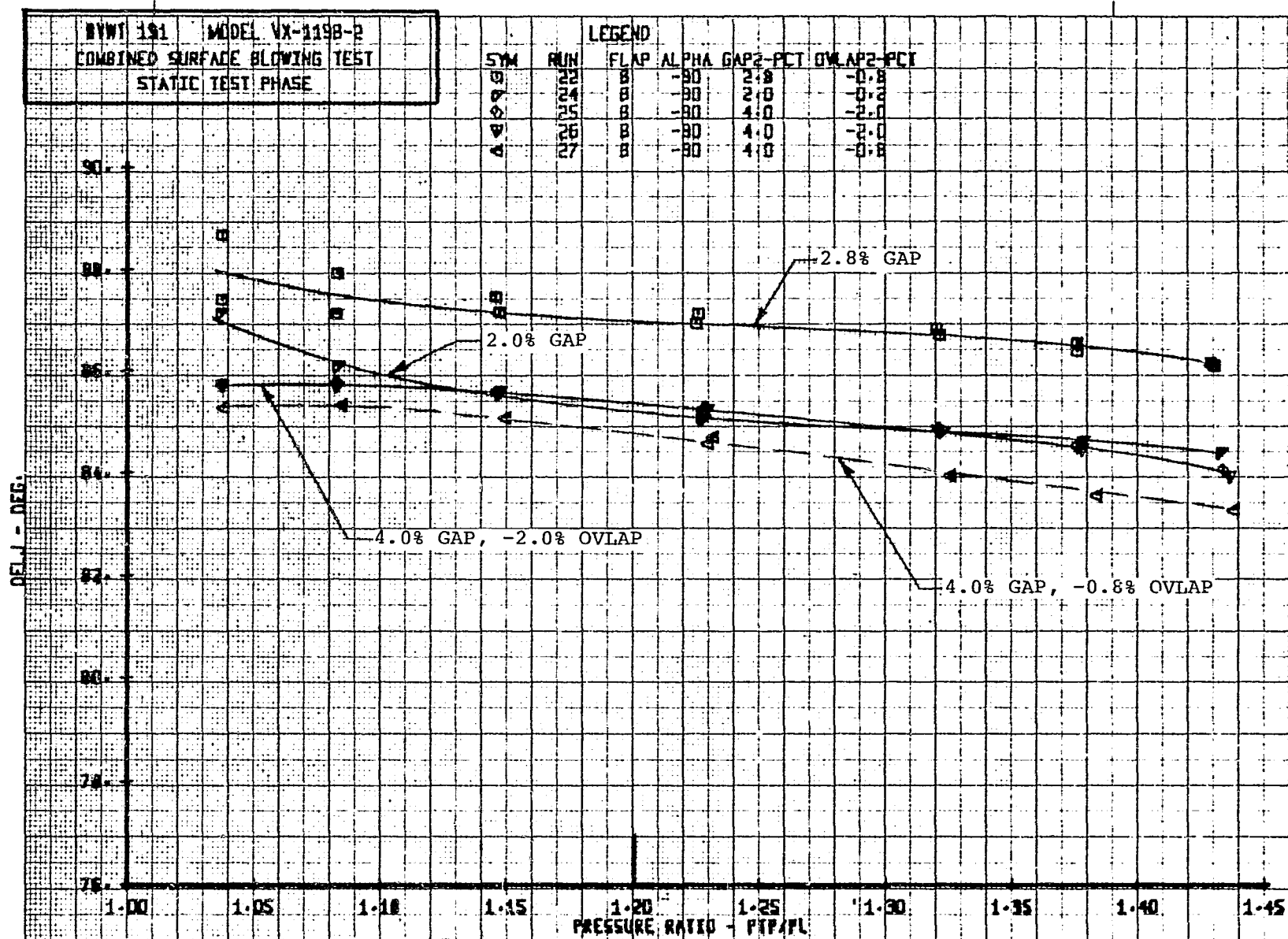
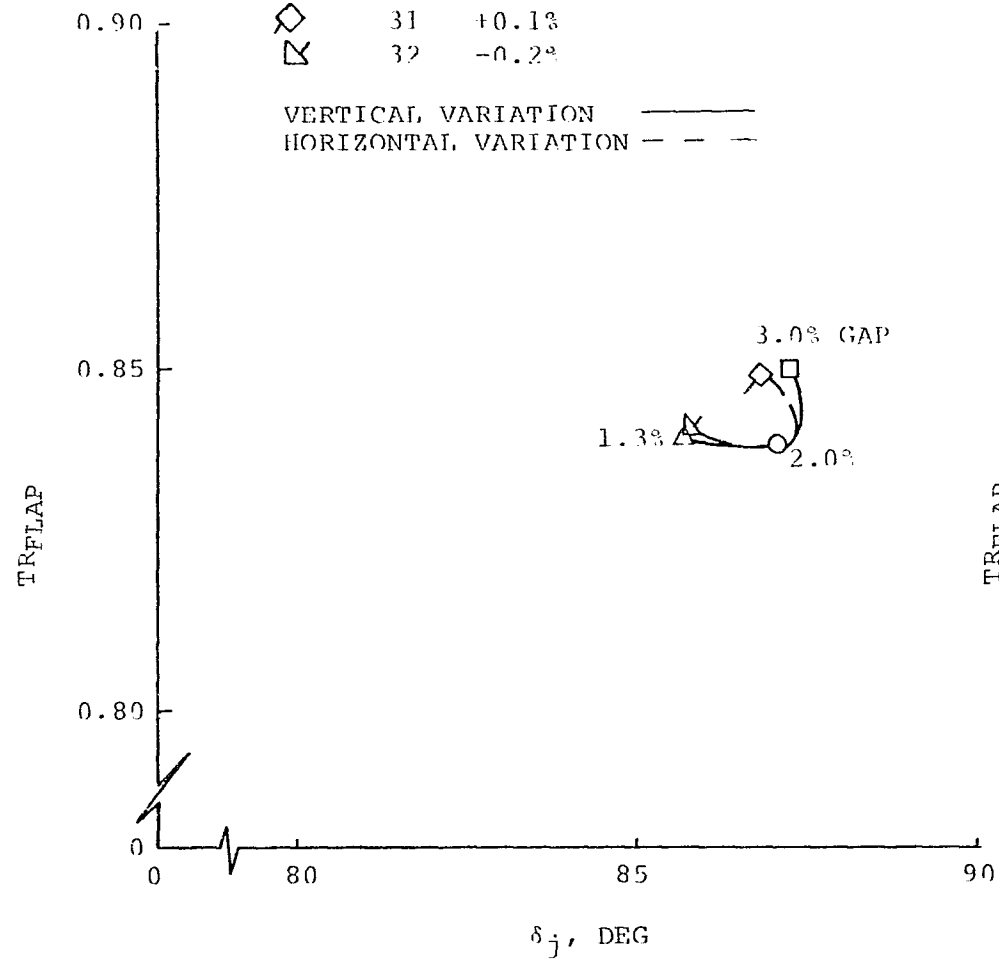


Figure 7.1-9. Flap B, Second Slot Variation

b. Thrust-Deflection Angle

SYM	RUN	OVLAP
○	22	-0.1%
□	28,29	-1.3%
△	30	+1.0%
◇	31	+0.1%
⊠	32	-0.2%

VERTICAL VARIATION ———
HORIZONTAL VARIATION - - -



1.2 PRESSURE RATIO

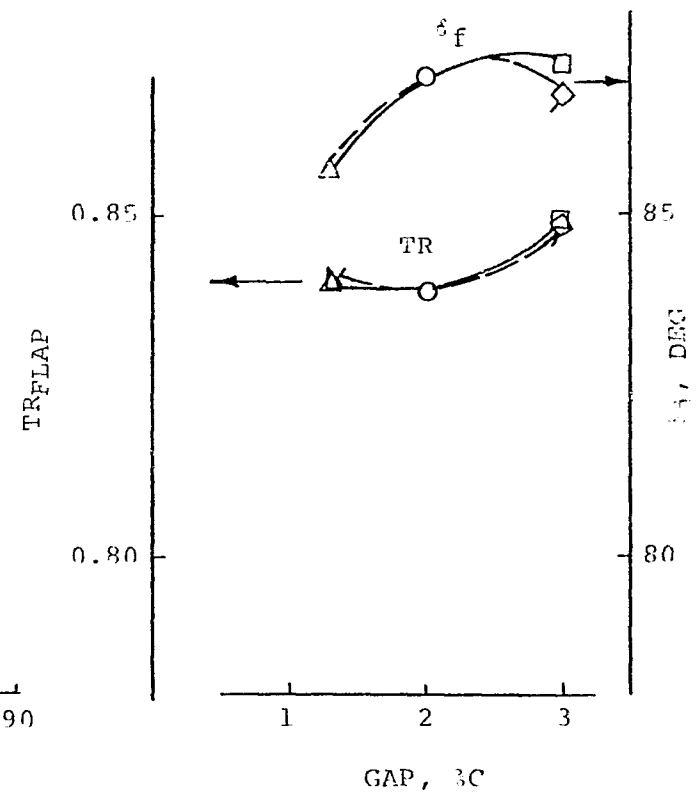


Figure 7.1-10. Flap B, Effect of Number 3 Gap

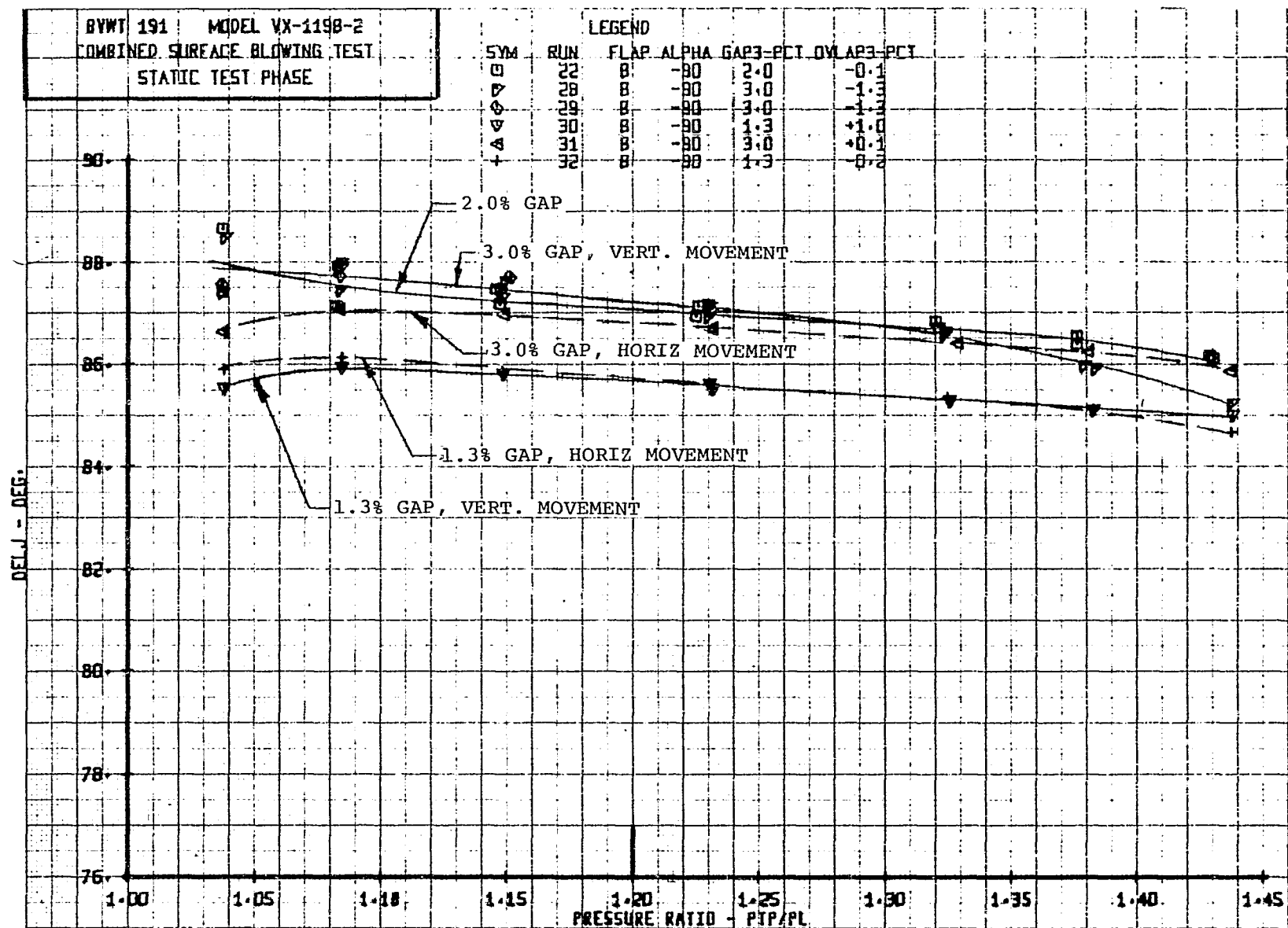


Figure 7.1-11. Flap B, Third Slot Variation

a. Thrust Recovery

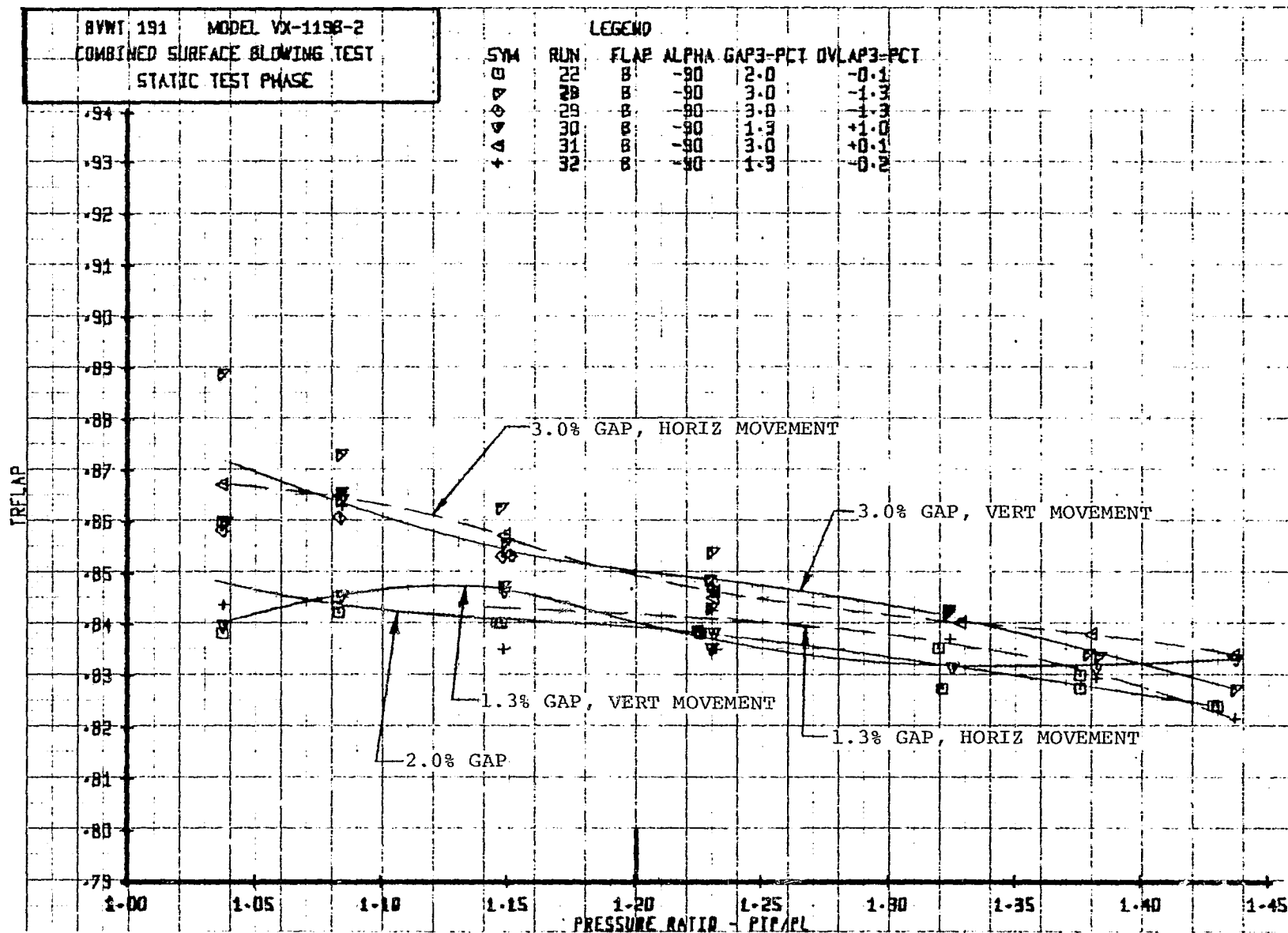


Figure 7.1-11. Flap B, Third Slot Variation
b. Thrust-Deflection Angle

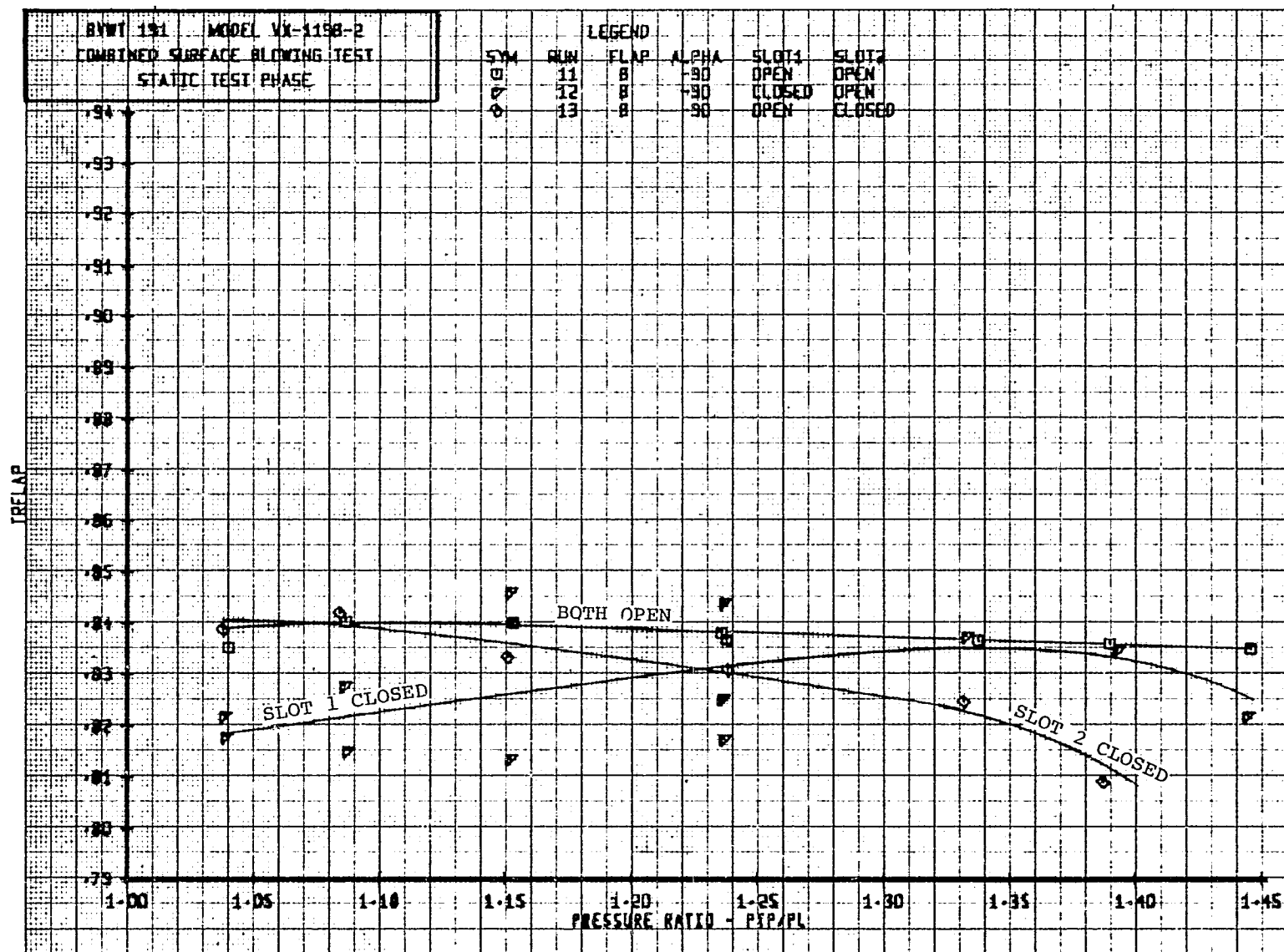


Figure 7.1-12. Effect of Closing Flap B Slots
a. Thrust Recovery

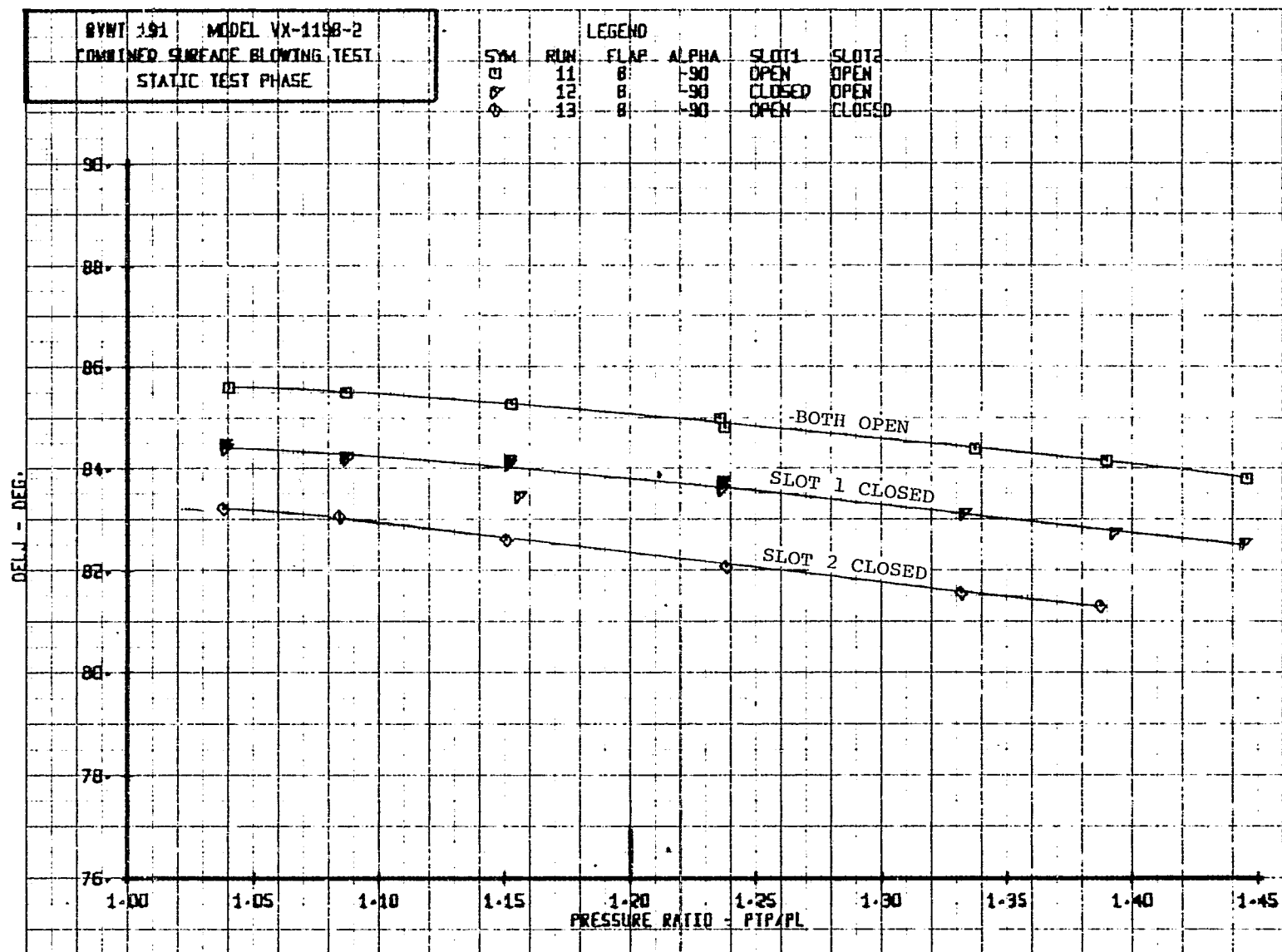


Figure 7.1-12. Effect of Closing Flap B Slots
b. Thrust-Deflection Angle

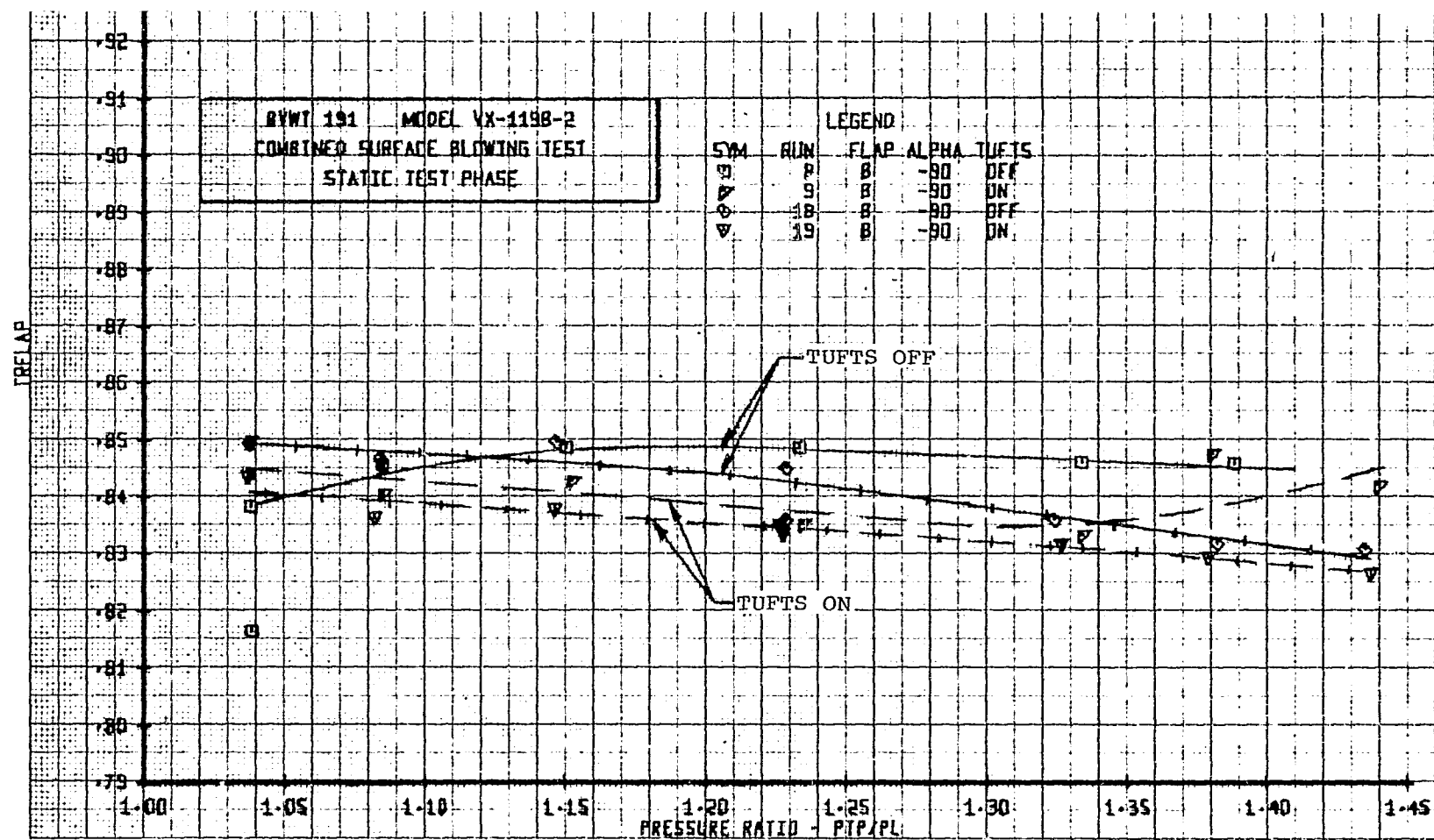


Figure 7.1-13. Effect of Tufts
a. Thrust Recovery

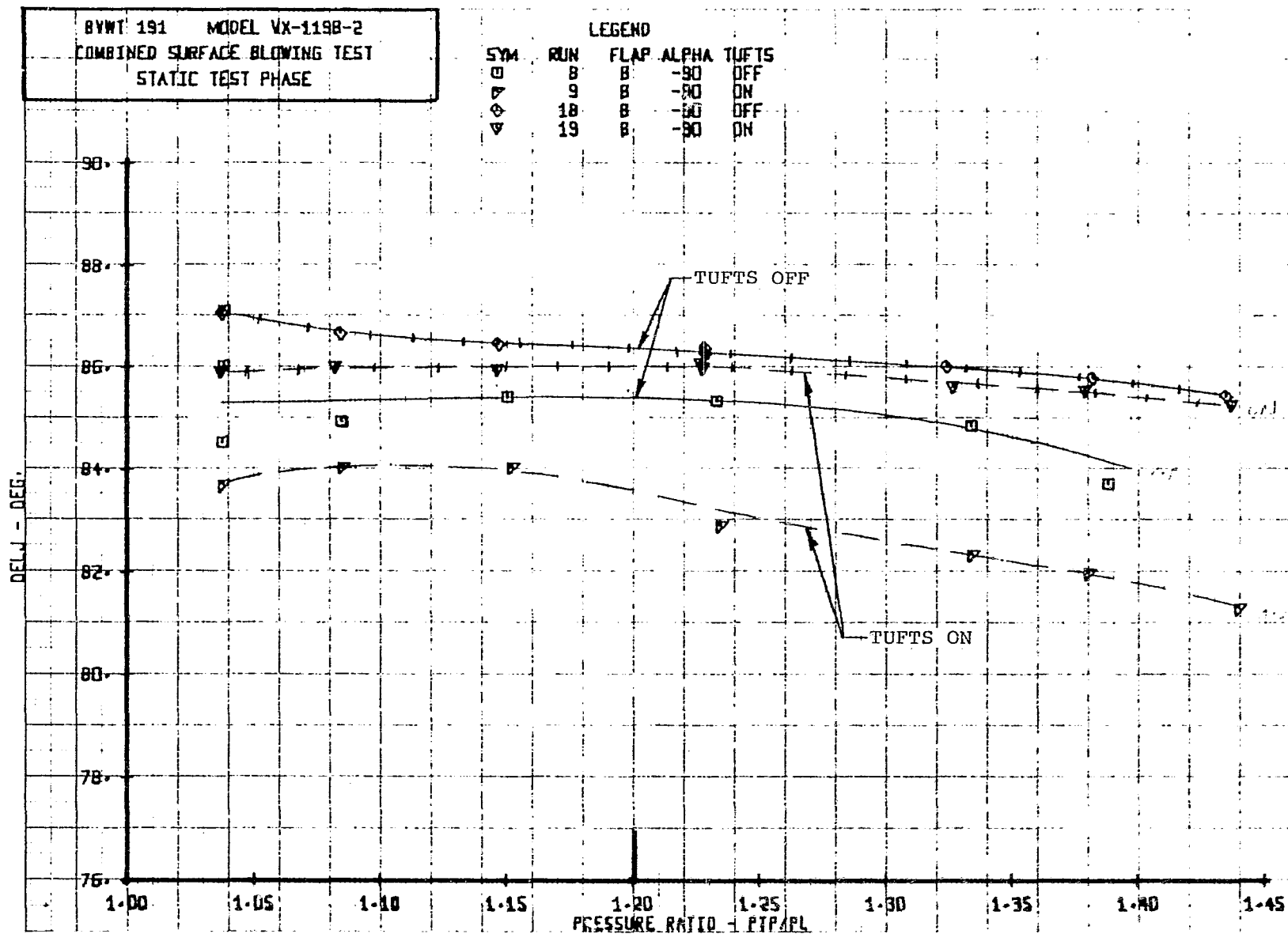
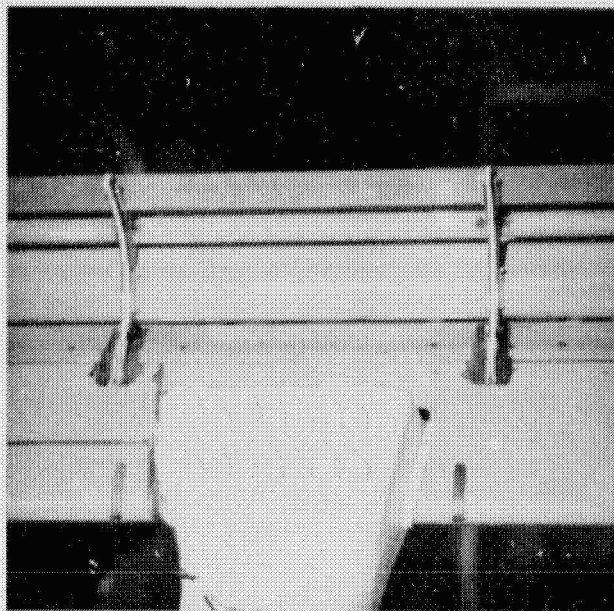


Figure 7.1-13. Effect of Tufts

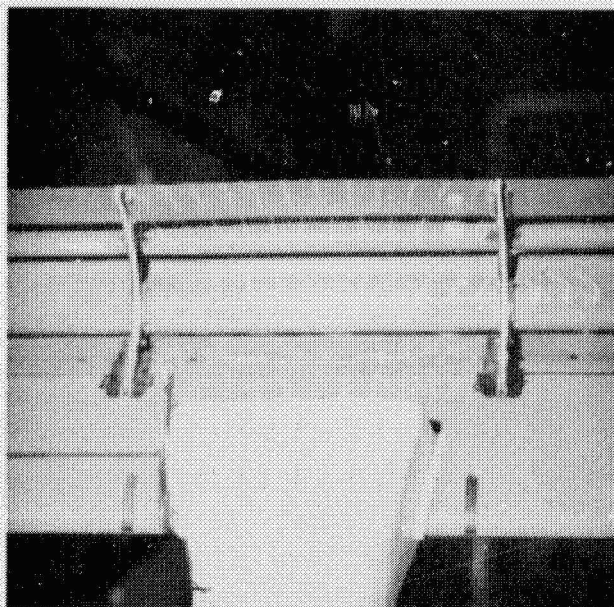
b. Thrust-Deflection Angle

LOWER SURFACE, EYEBROWS OFF



CHINA CLAY

189577-5



TUFTS

189557-4

Figure 7.1-14. Static-Flow Visualization with Flap B

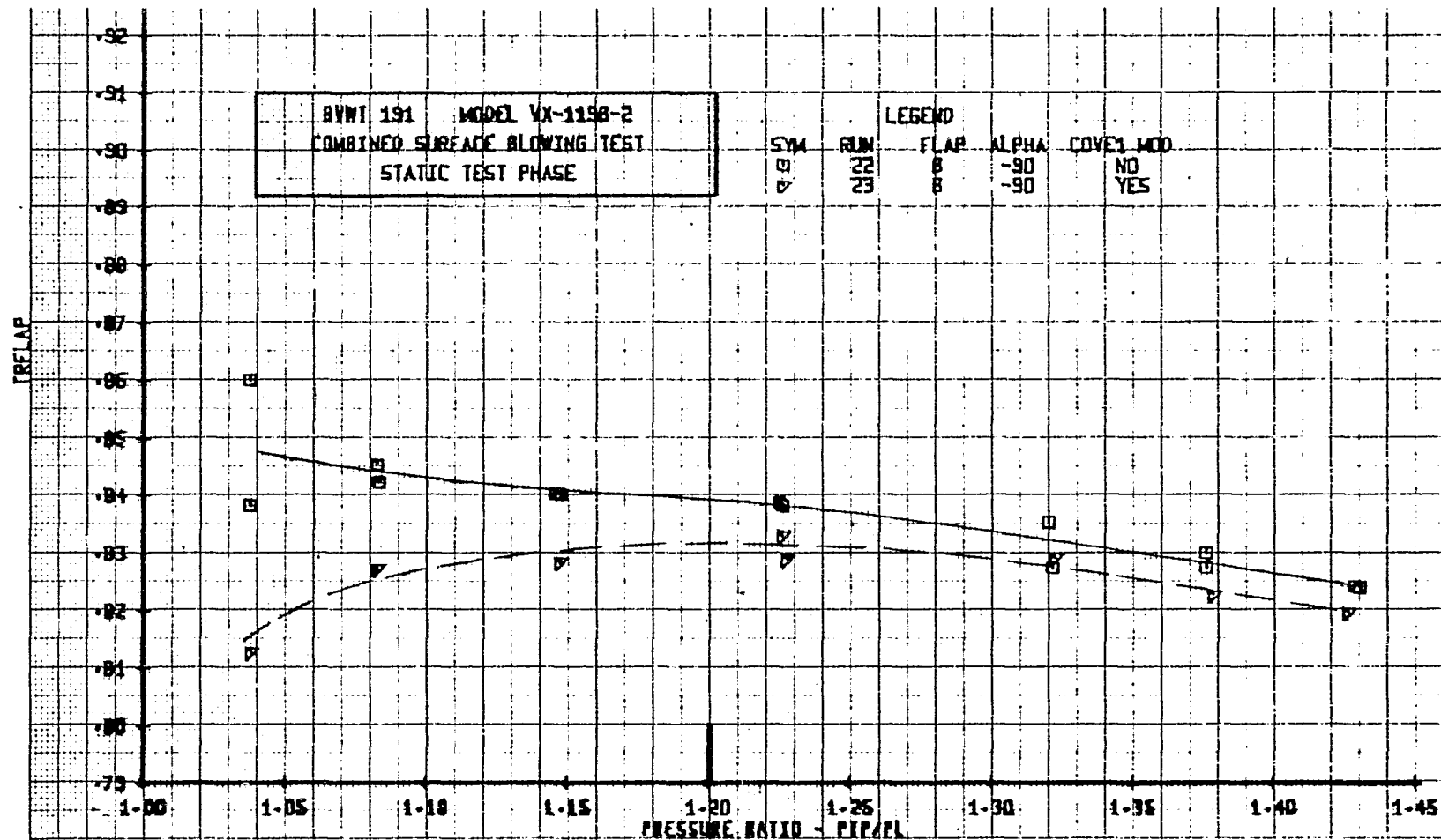


Figure 7.1-15. Flap B, First Slot Cove Modification
a. Thrust Recovery

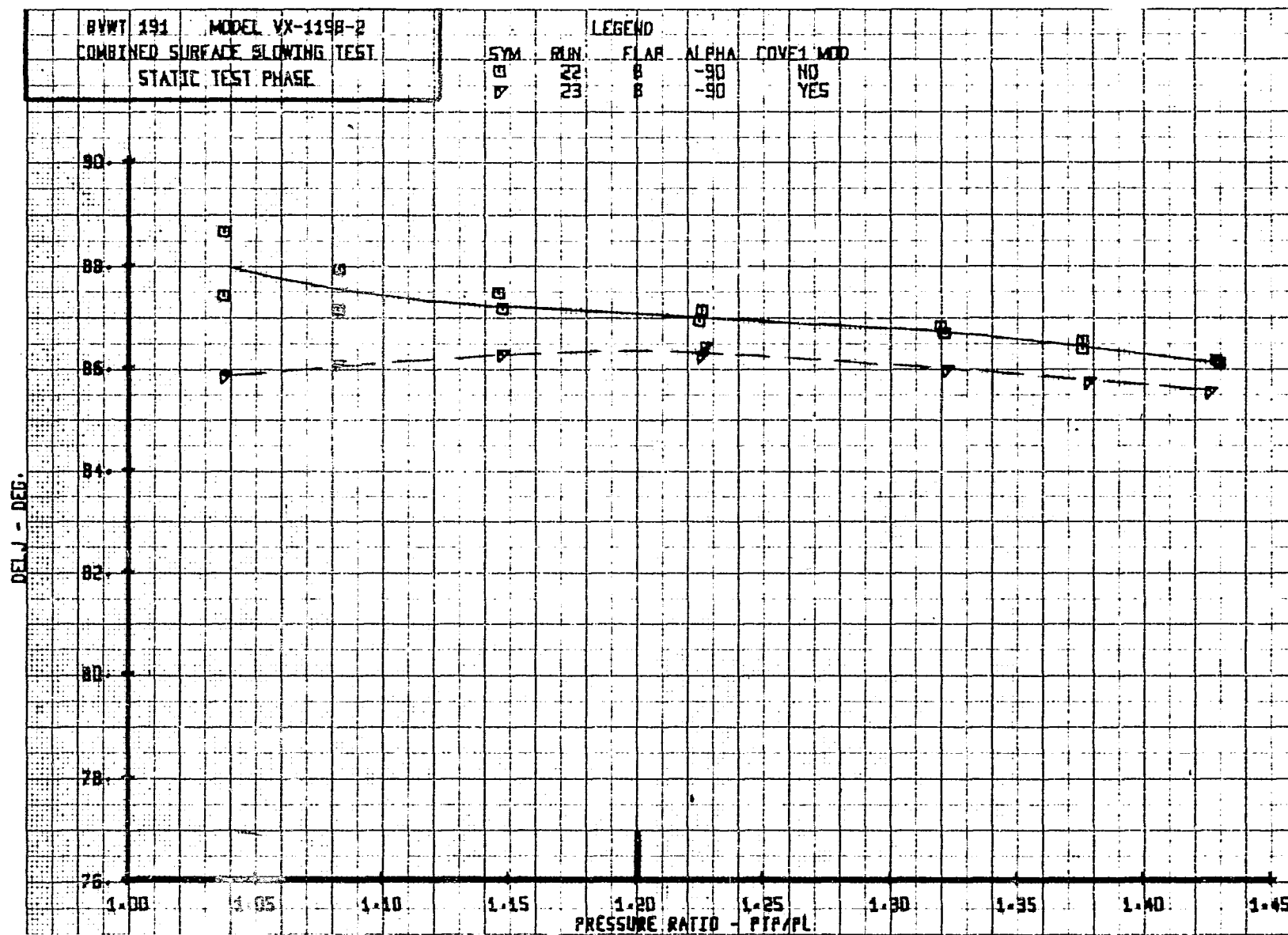


Figure 7.1-15. Flap B, First Slot Cove Modification
b. Thrust-Deflection Angle

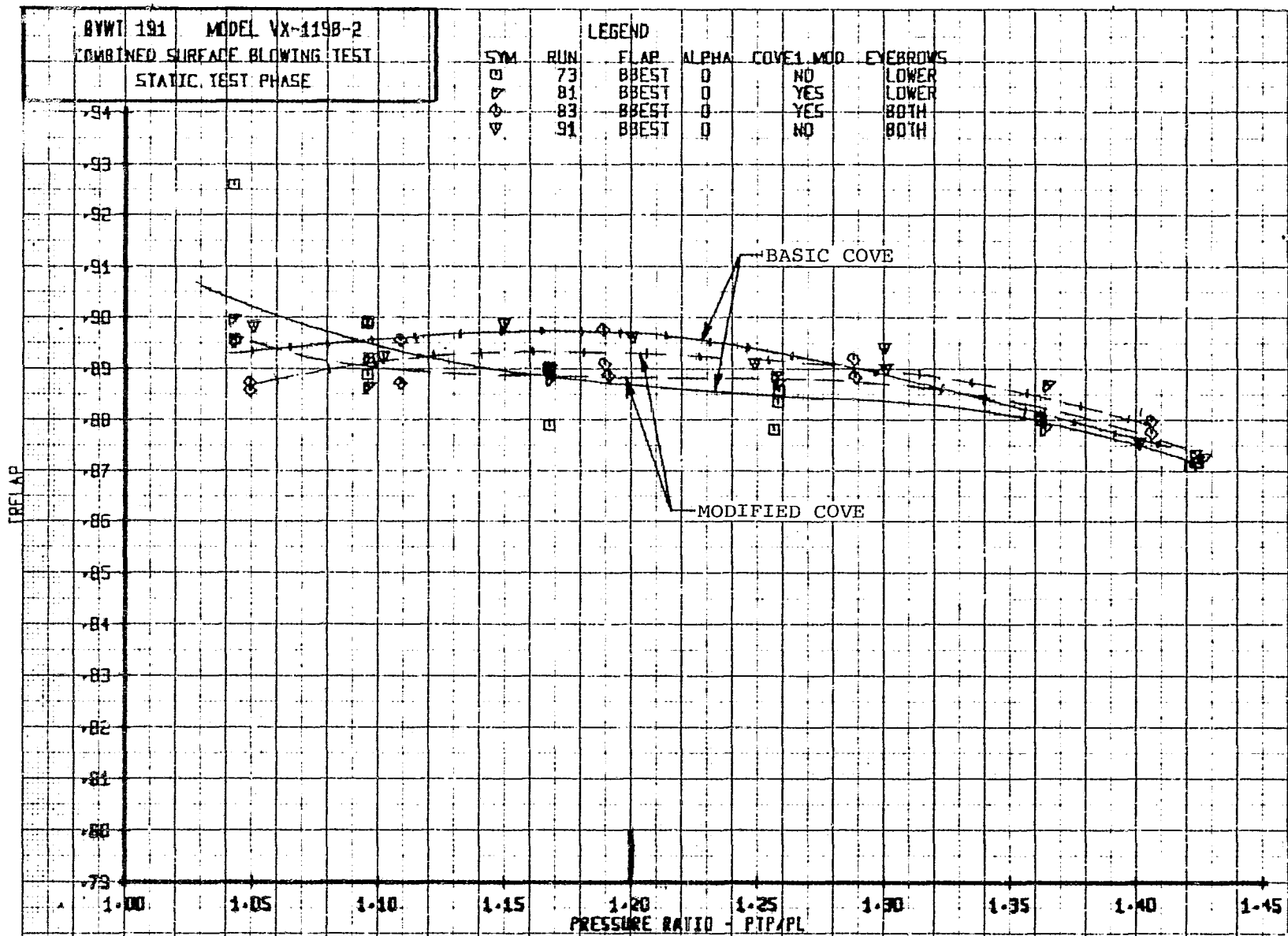
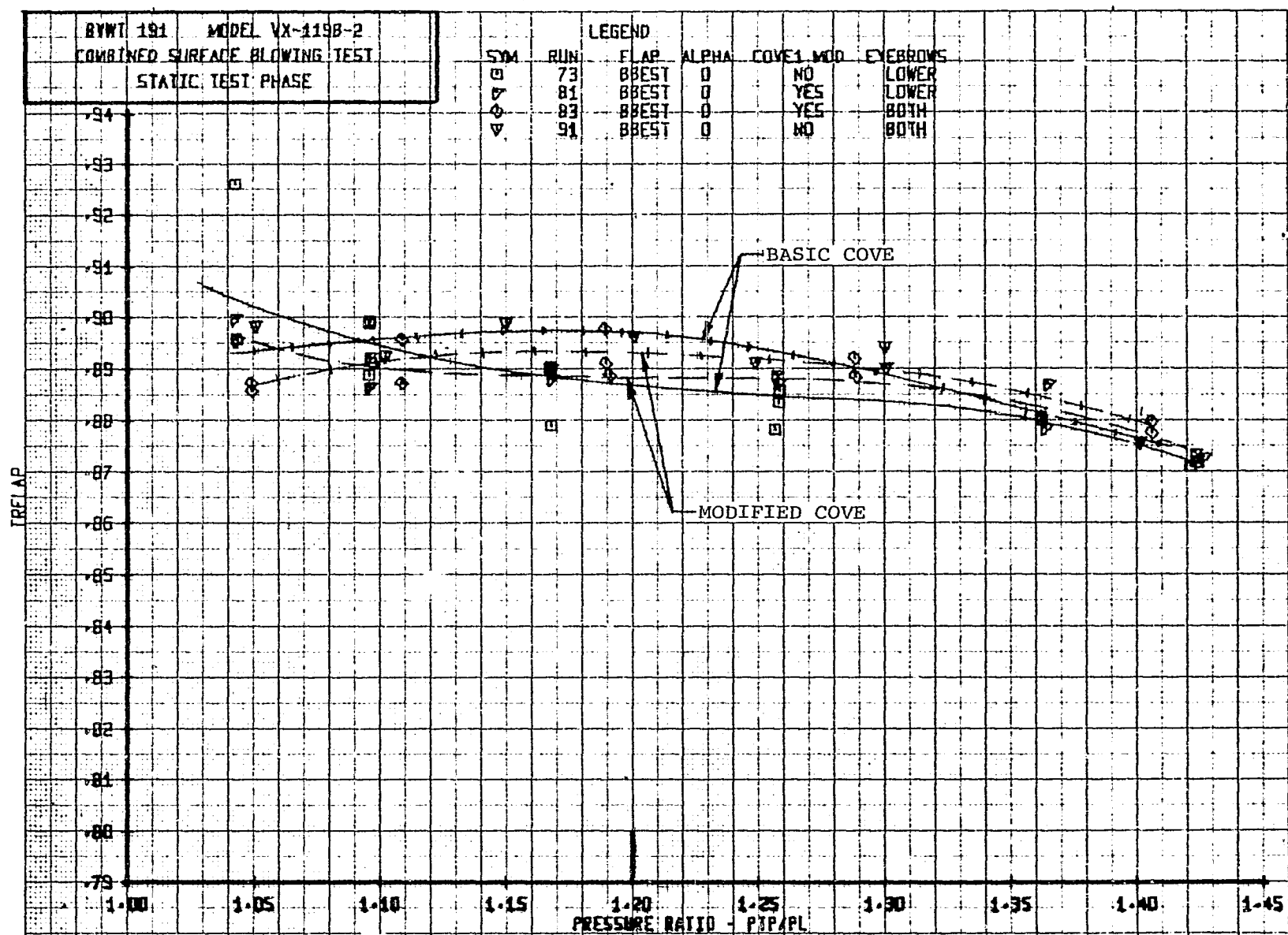


Figure 7.1-16. Flap B, First Cove Modification

a. Thrust Recovery



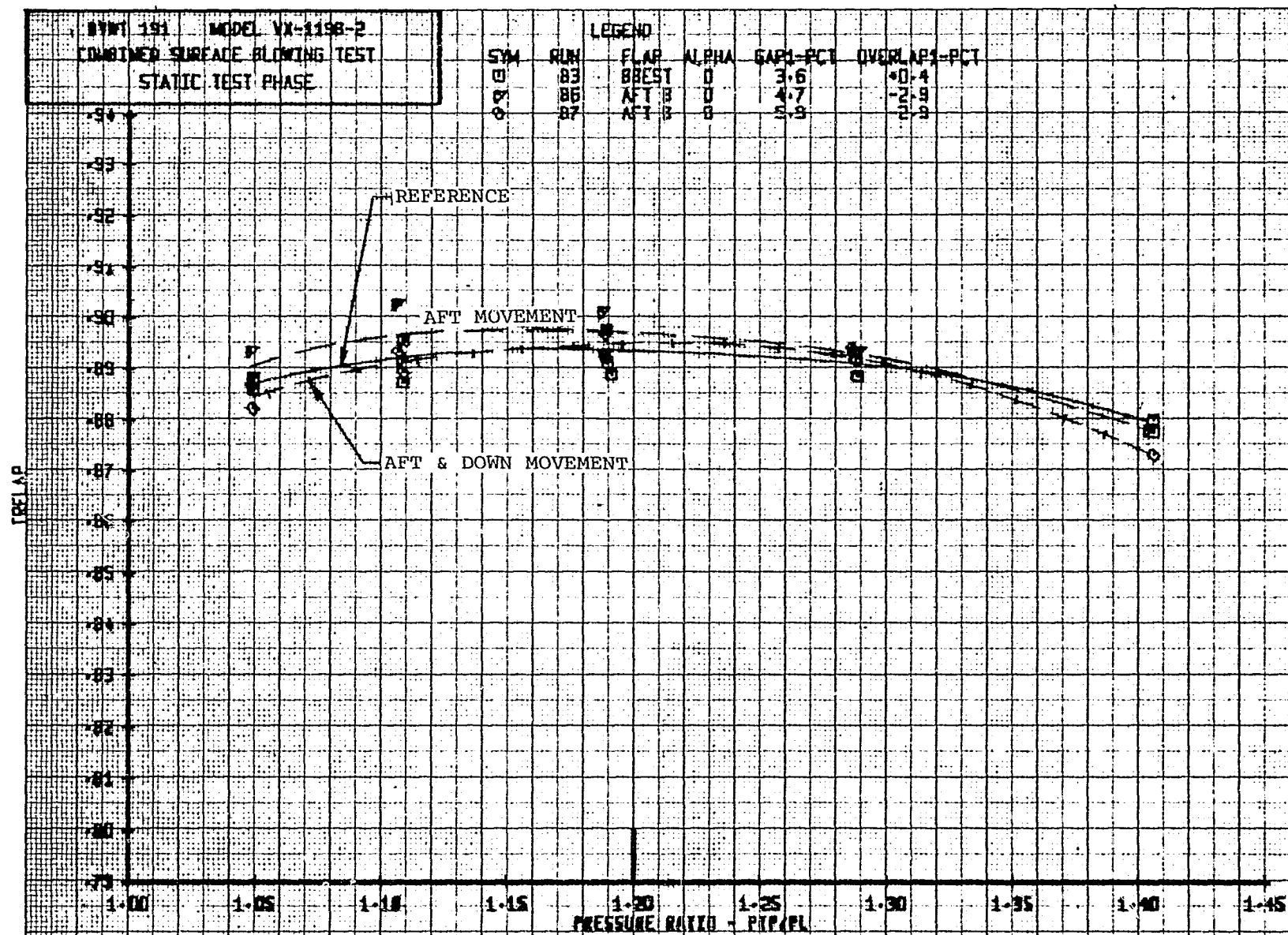


Figure 7.1-17. Flap B, Effect of Aft Flap Movement
 a. Thrust Recovery

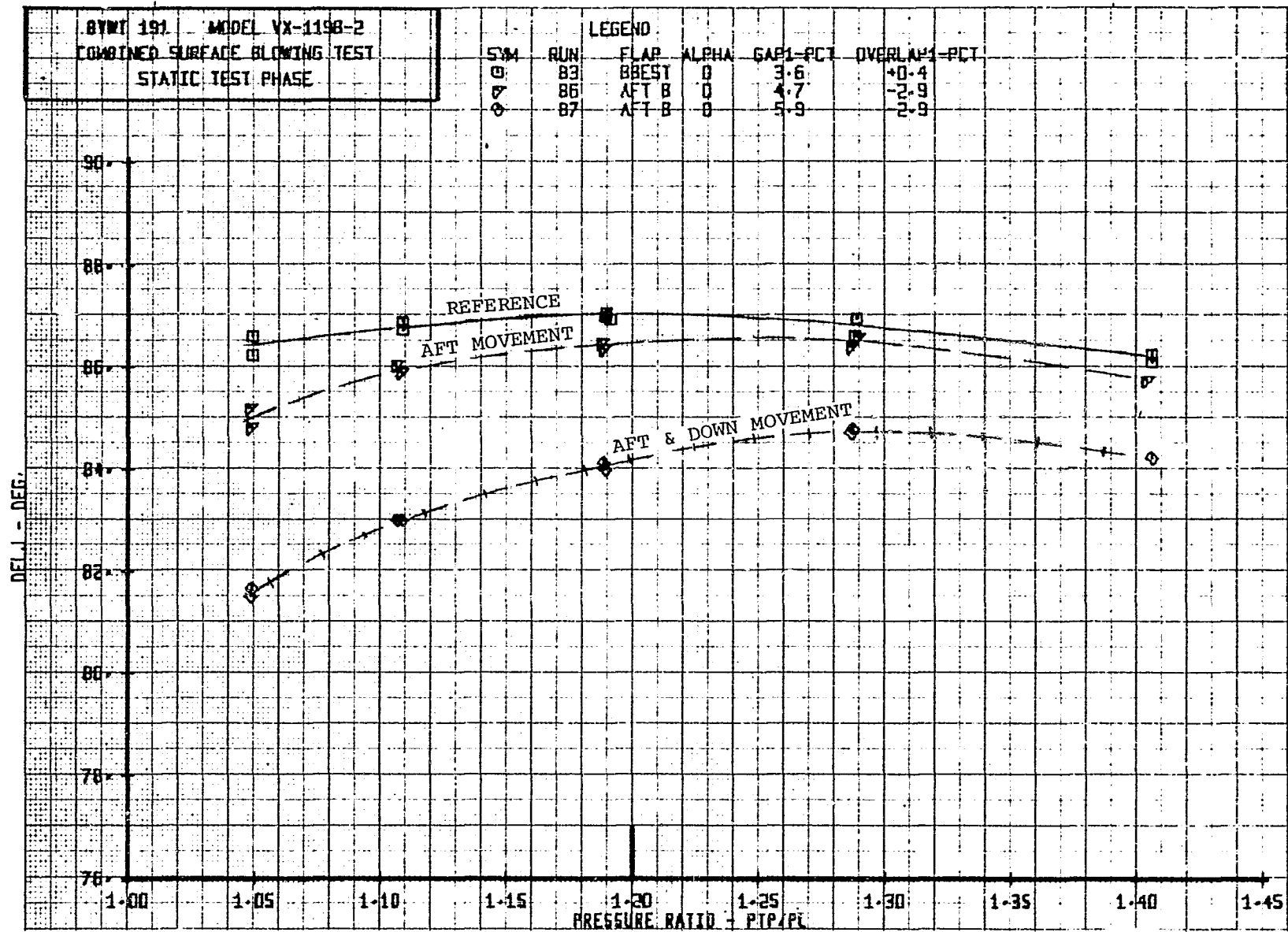
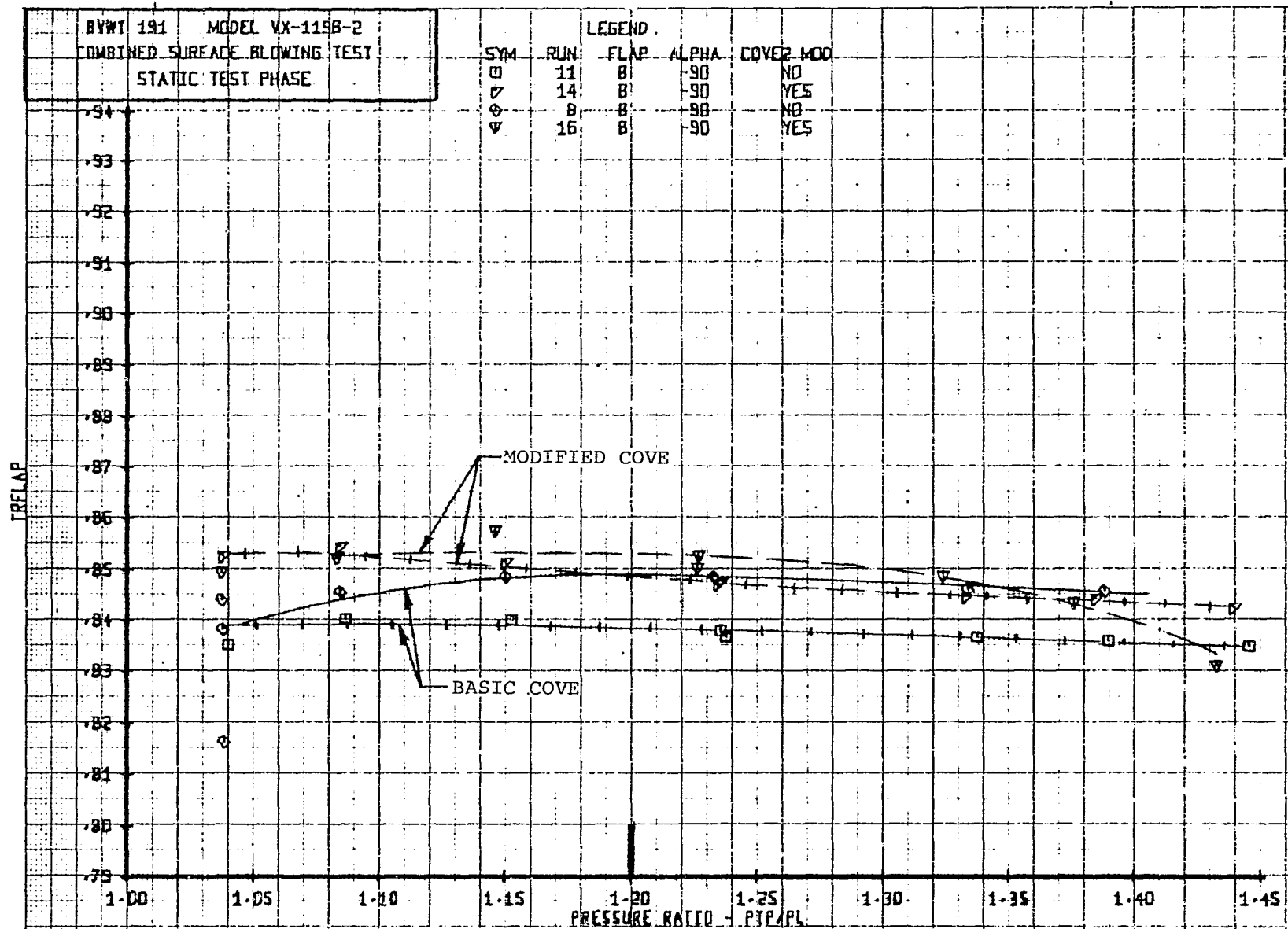


Figure 7.1-17. Flap B, Effect of Aft Flap Movement
b. Thrust-Deflection Angle



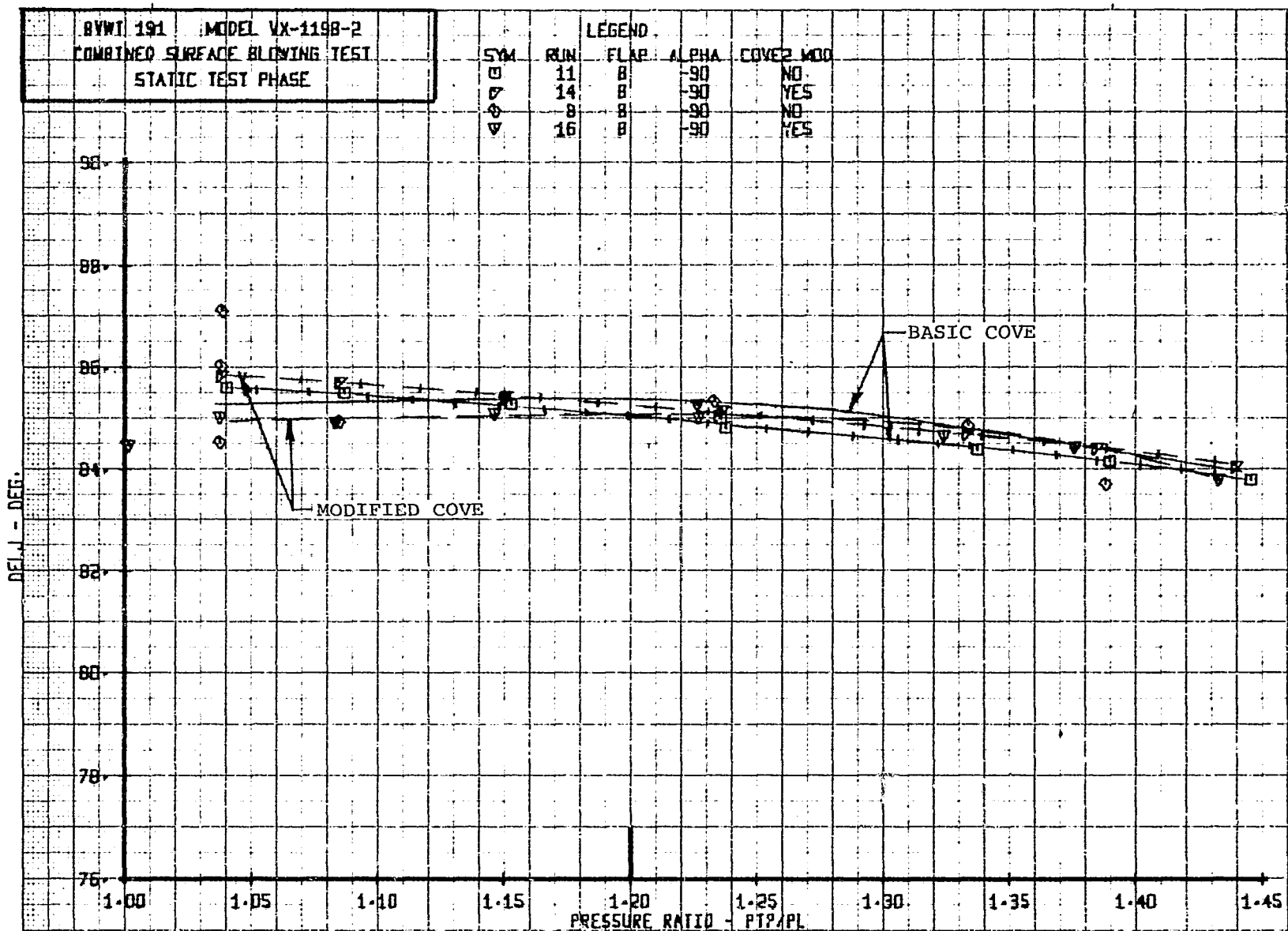


Figure 7.1-18. Flap B, Second Cove Modification

b. Thrust-Deflection Angle

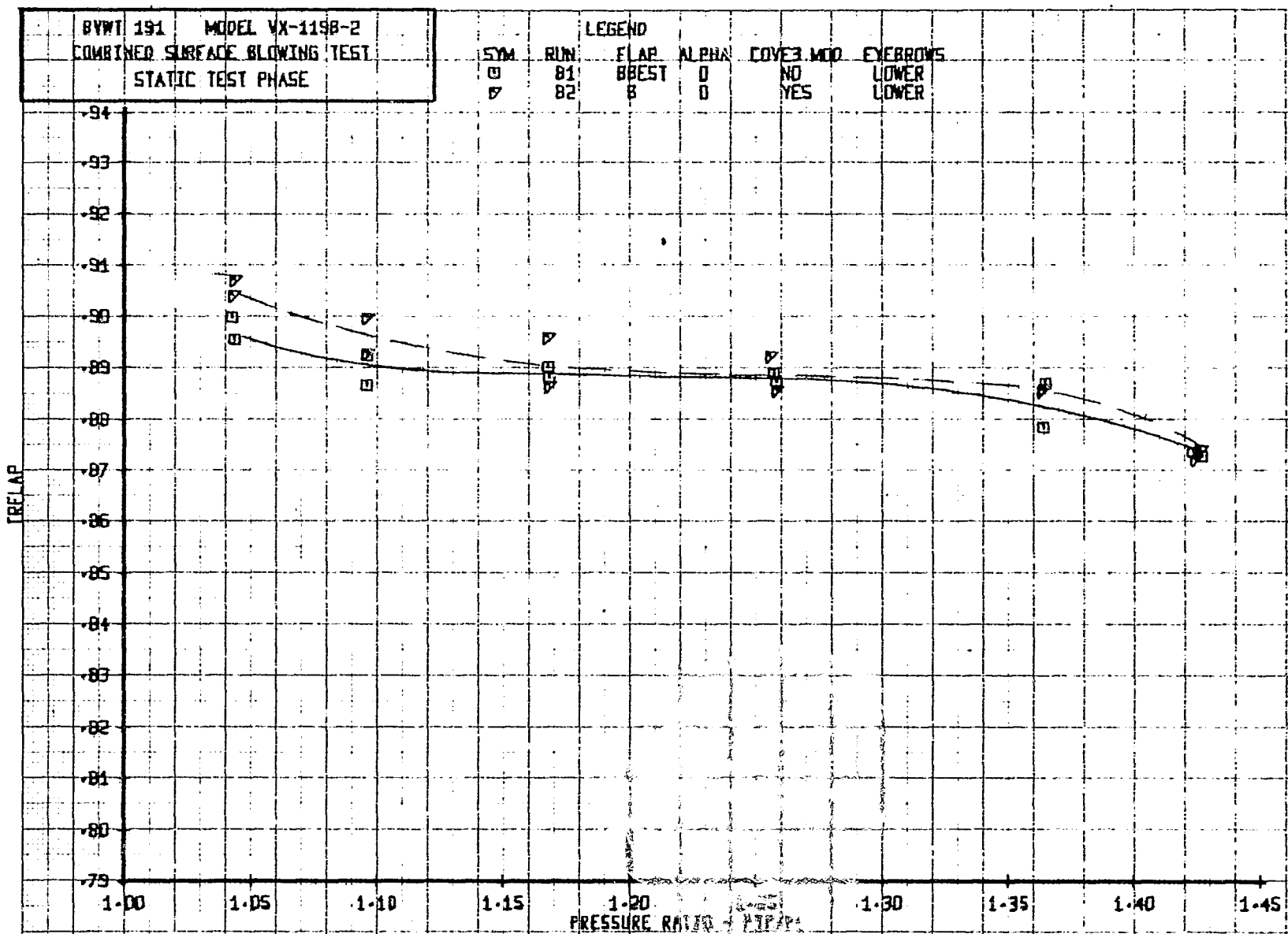


Figure 7.1-19. Flap B, Third Slot Cove Modification
a. Thrust Recovery

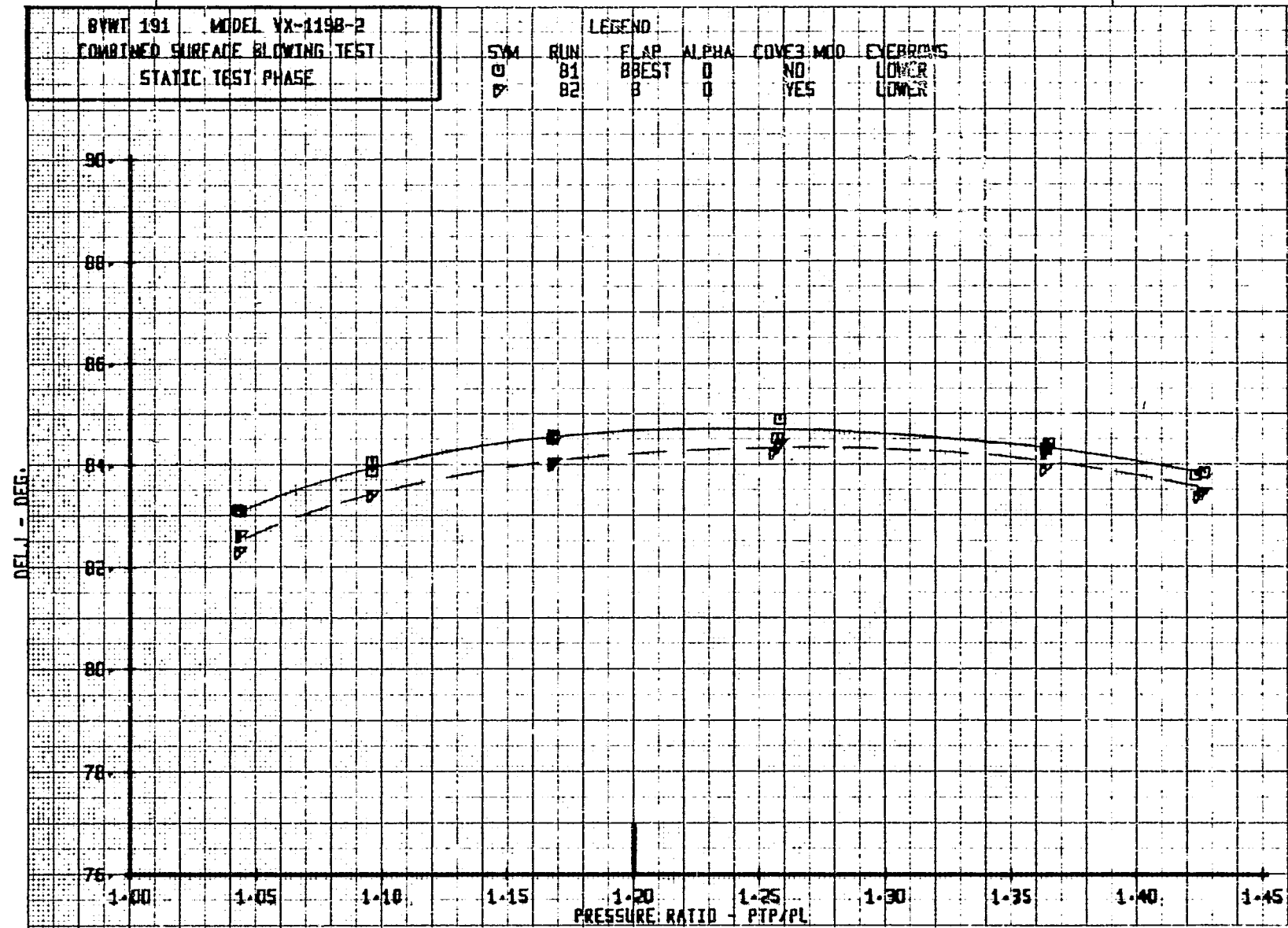


Figure 7.1-19. Flap B, Third Slot Cover Modification
b. Thrust-Deflection Angle

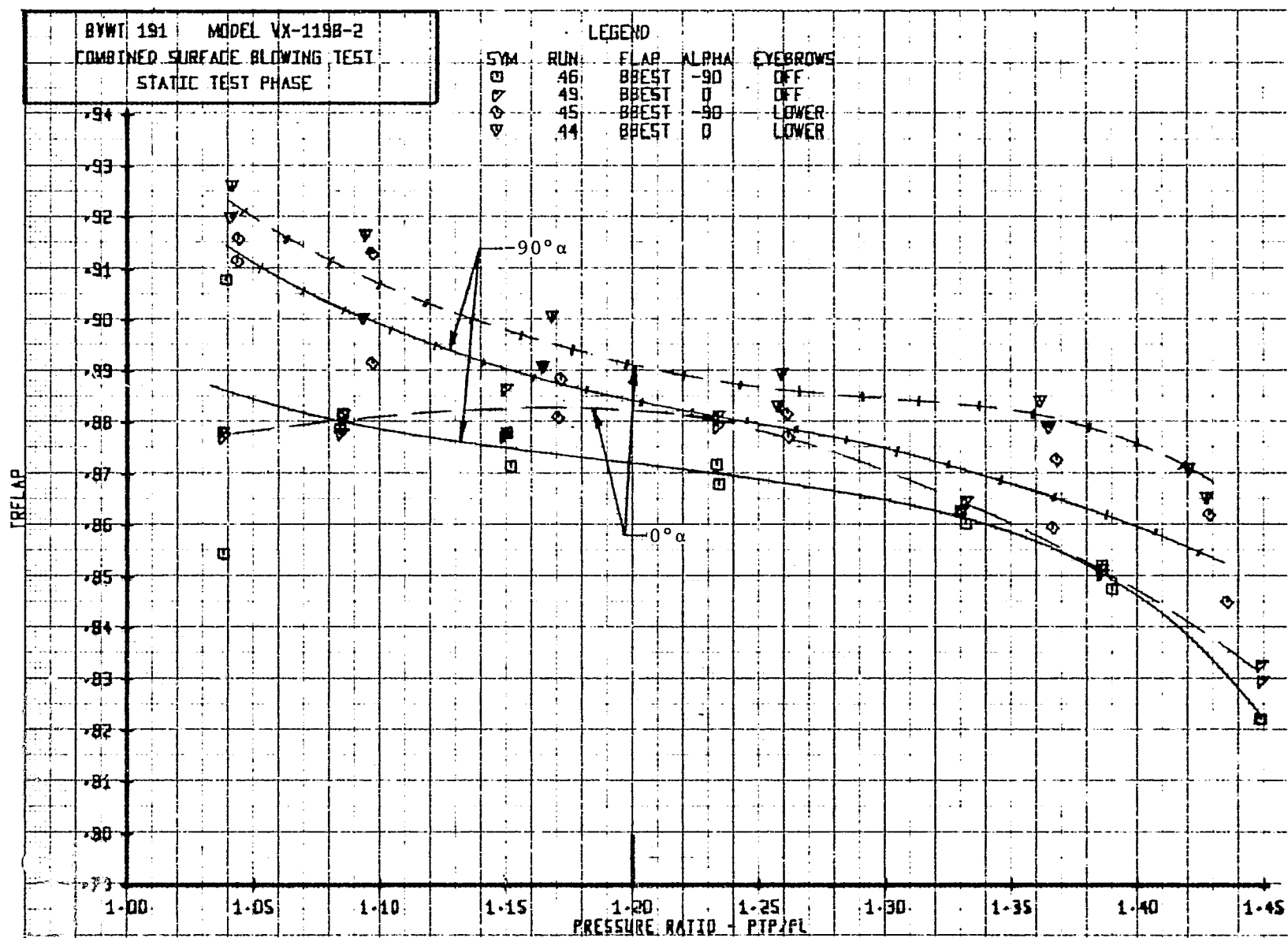


Figure 7.1-20. Flap B, Effect of Model Orientation and Lower Eyebrows
a. Thrust Recovery

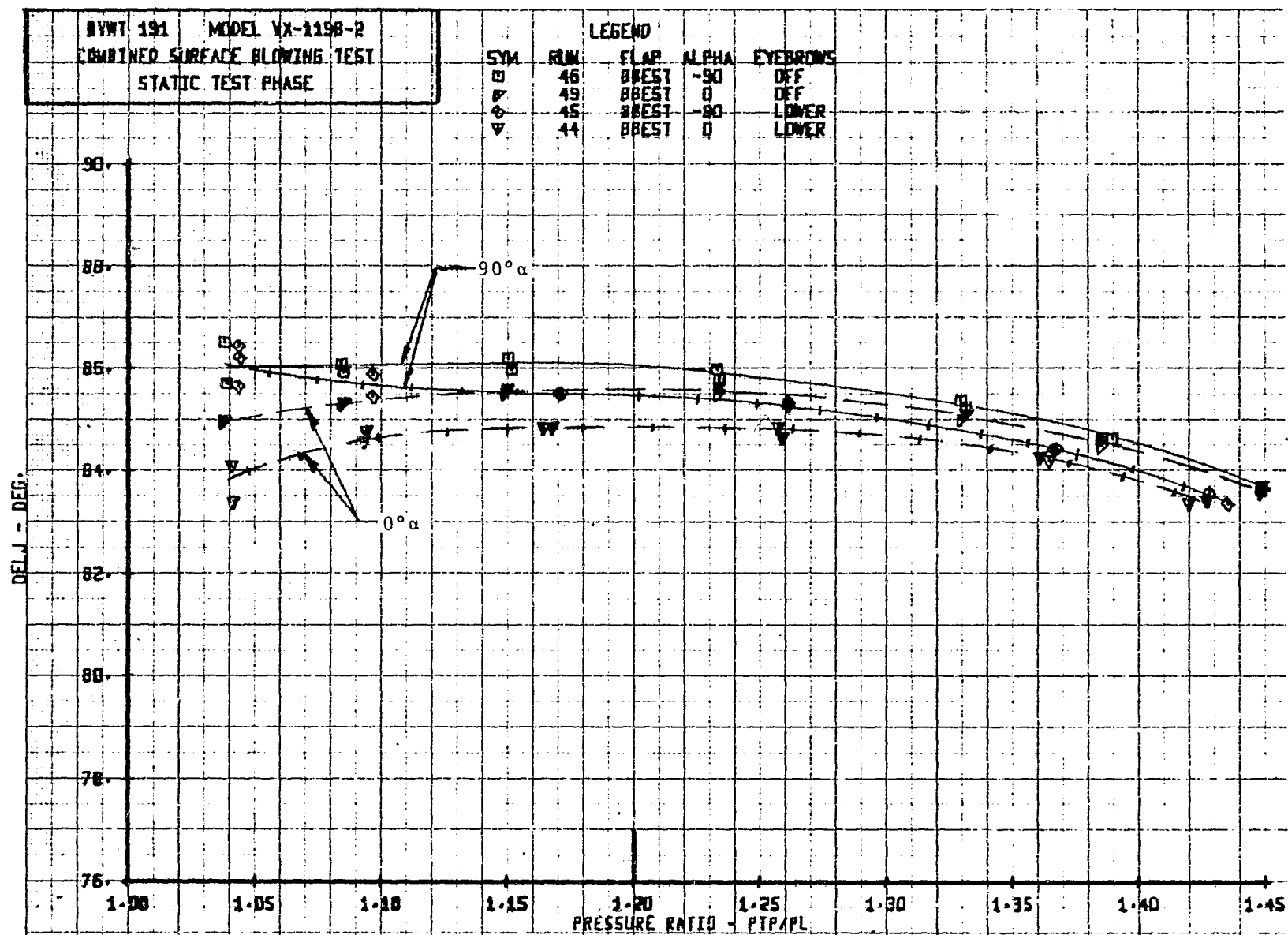


Figure 7.1-20. Flap B, Effect of Model Orientation and Lower Eyebrows
 b. Thrust-Deflection Angle

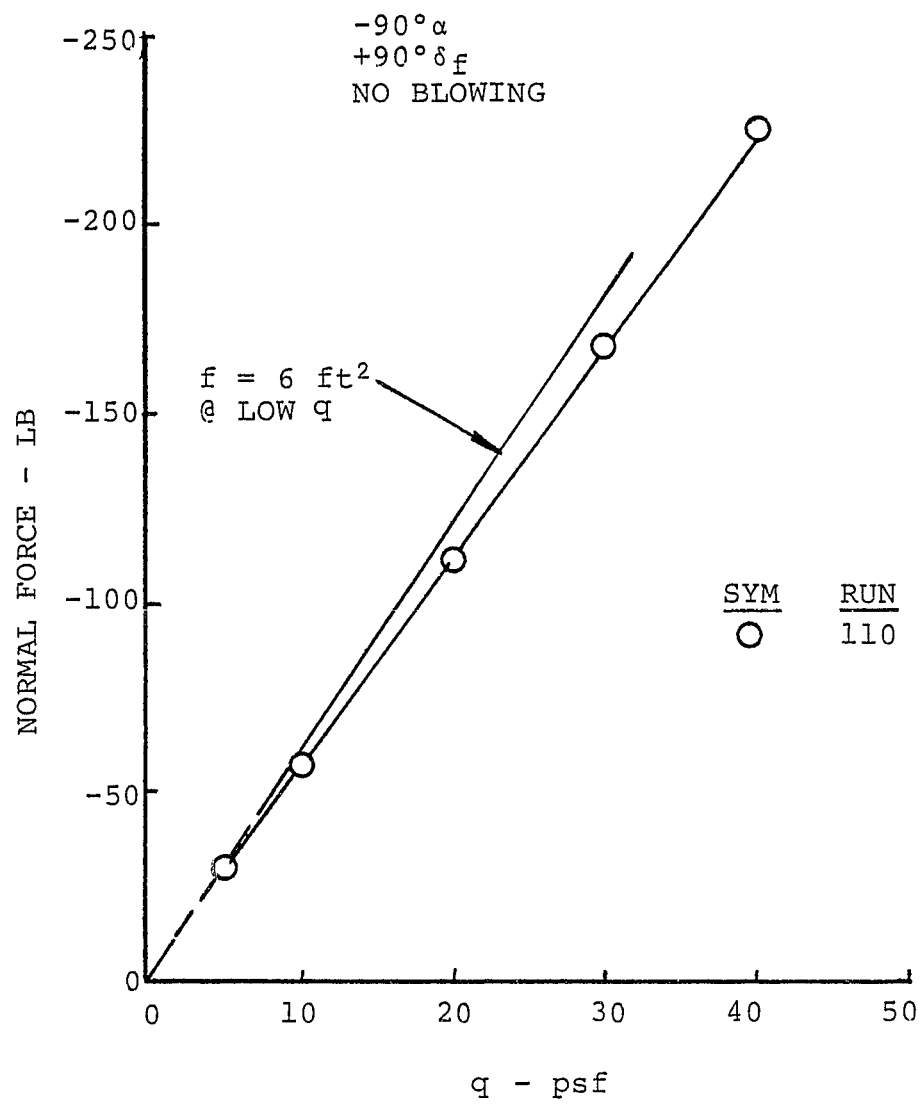


Figure 7.1-21. Model Cross-Flow Drag with $\delta_f = 90^\circ$

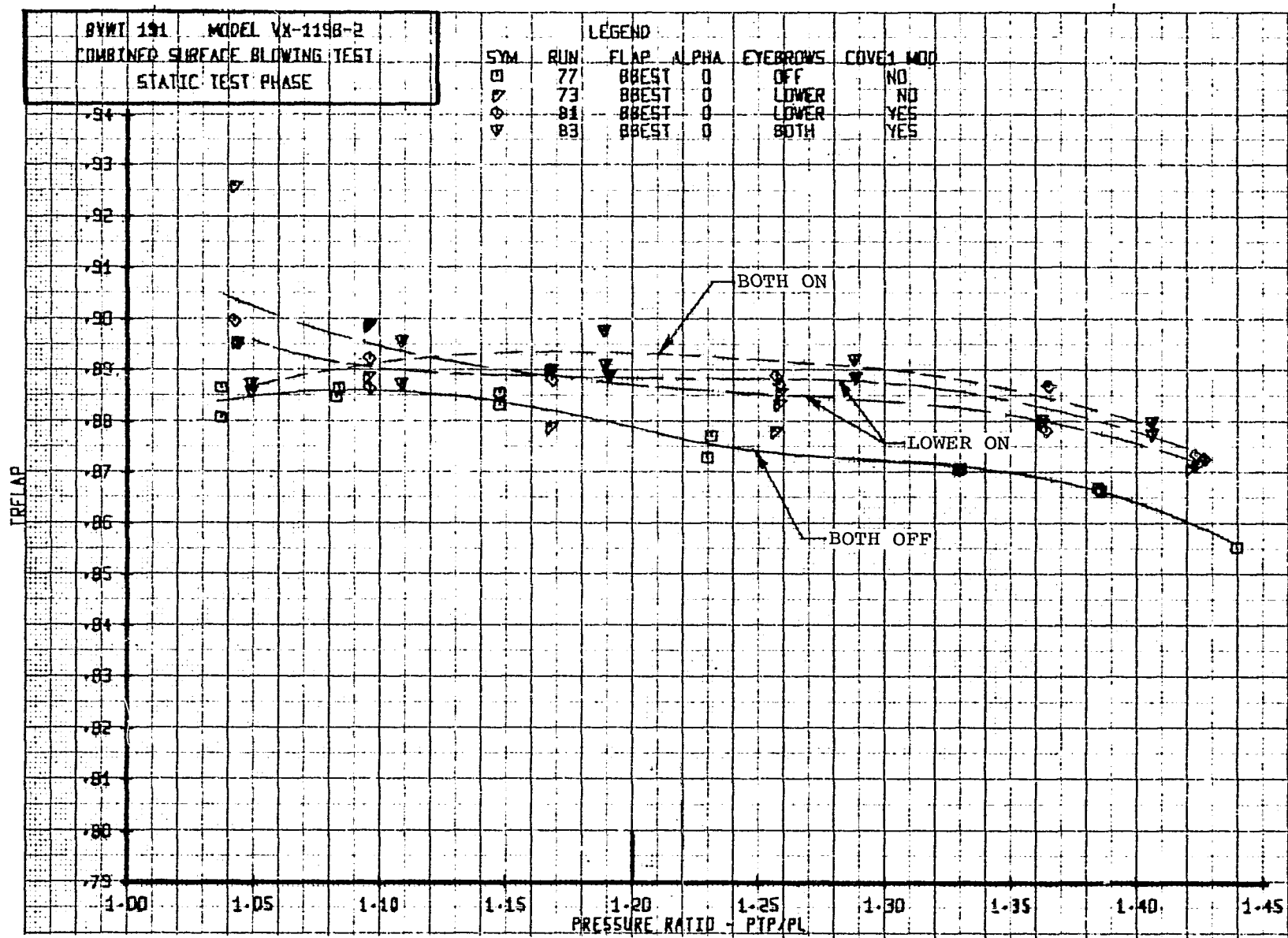


Figure 7.1-22. Flap B, Effect of Eyebrows

a. Thrust Recovery

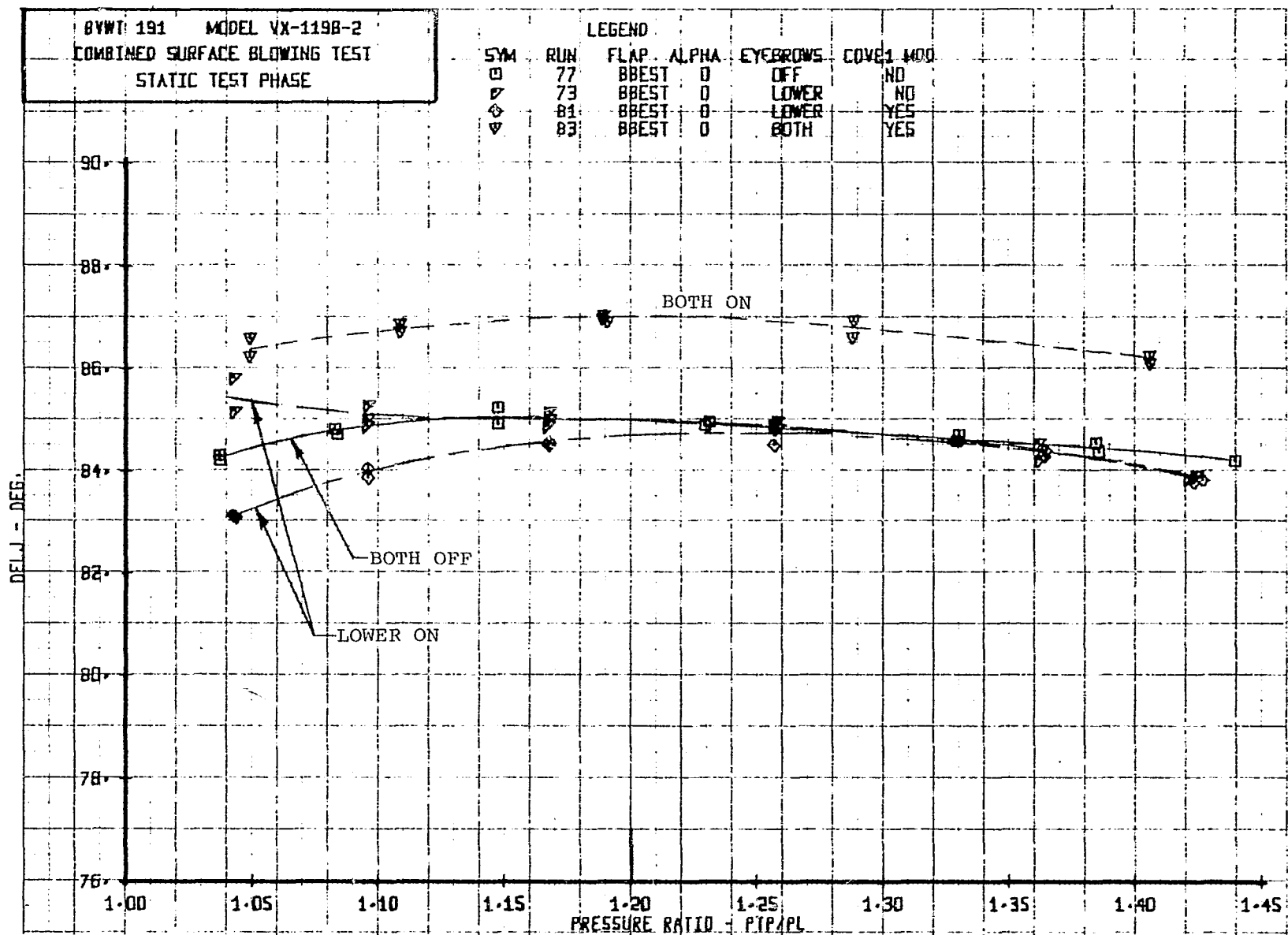


Figure 7.1-22. Flap B, Effect of Eyebrows
b. Thrust-Deflection Angle

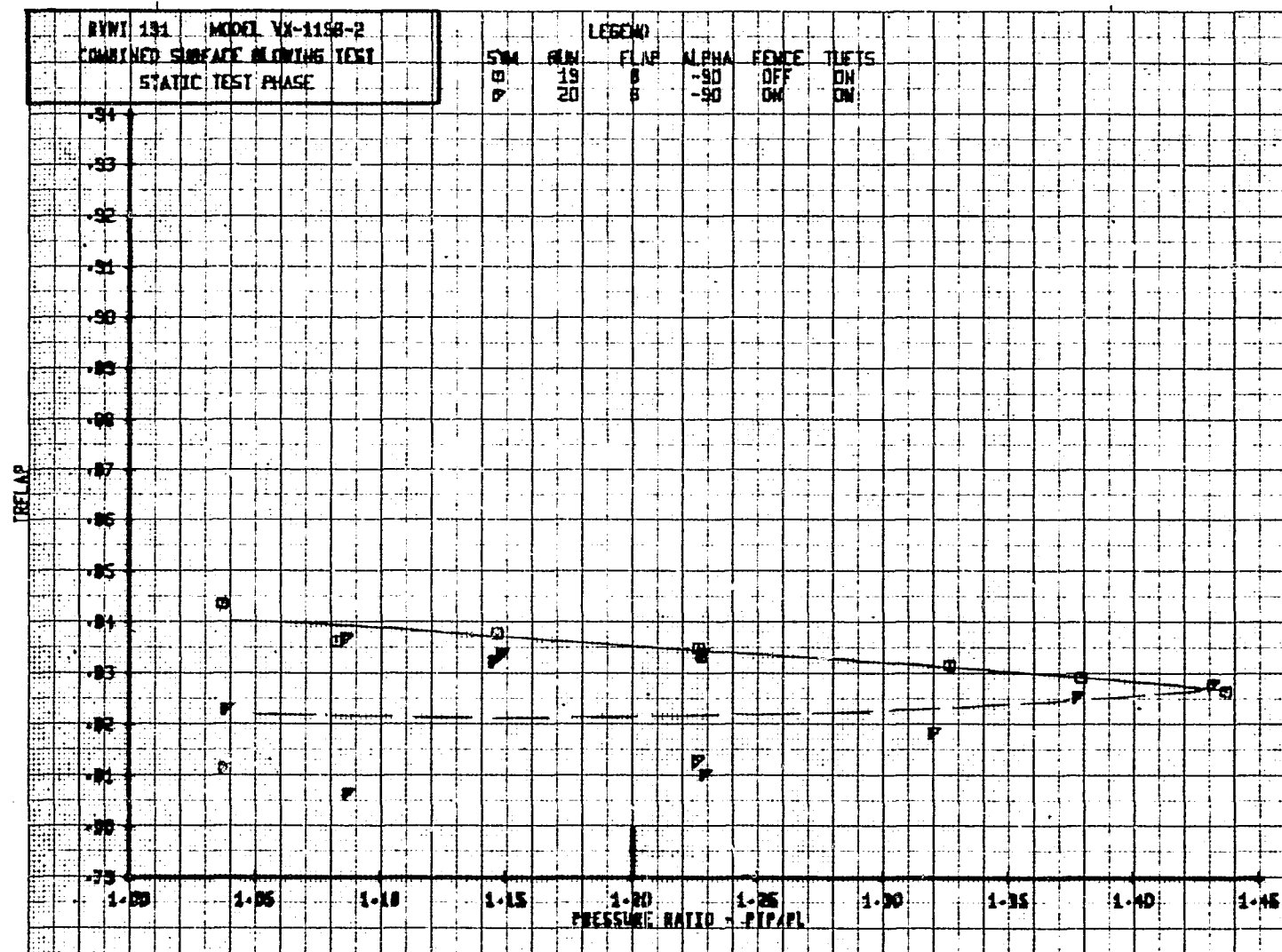


Figure 7.1-23. Flap B, Lower Fence Addition
a. Thrust Recovery

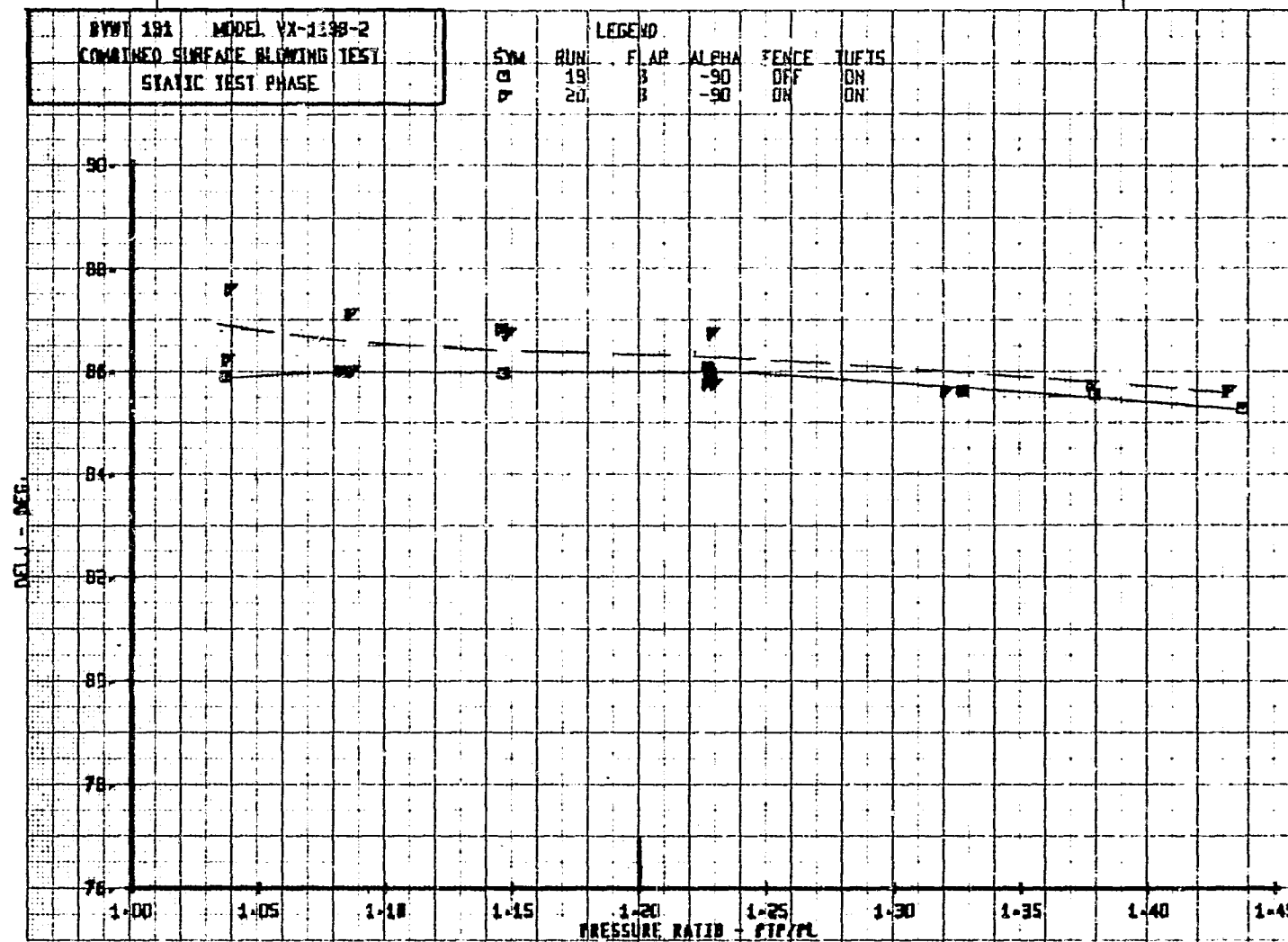


Figure 7.1-23. Flap B, Lower Fence Addition
b. Thrust-Deflection Angle

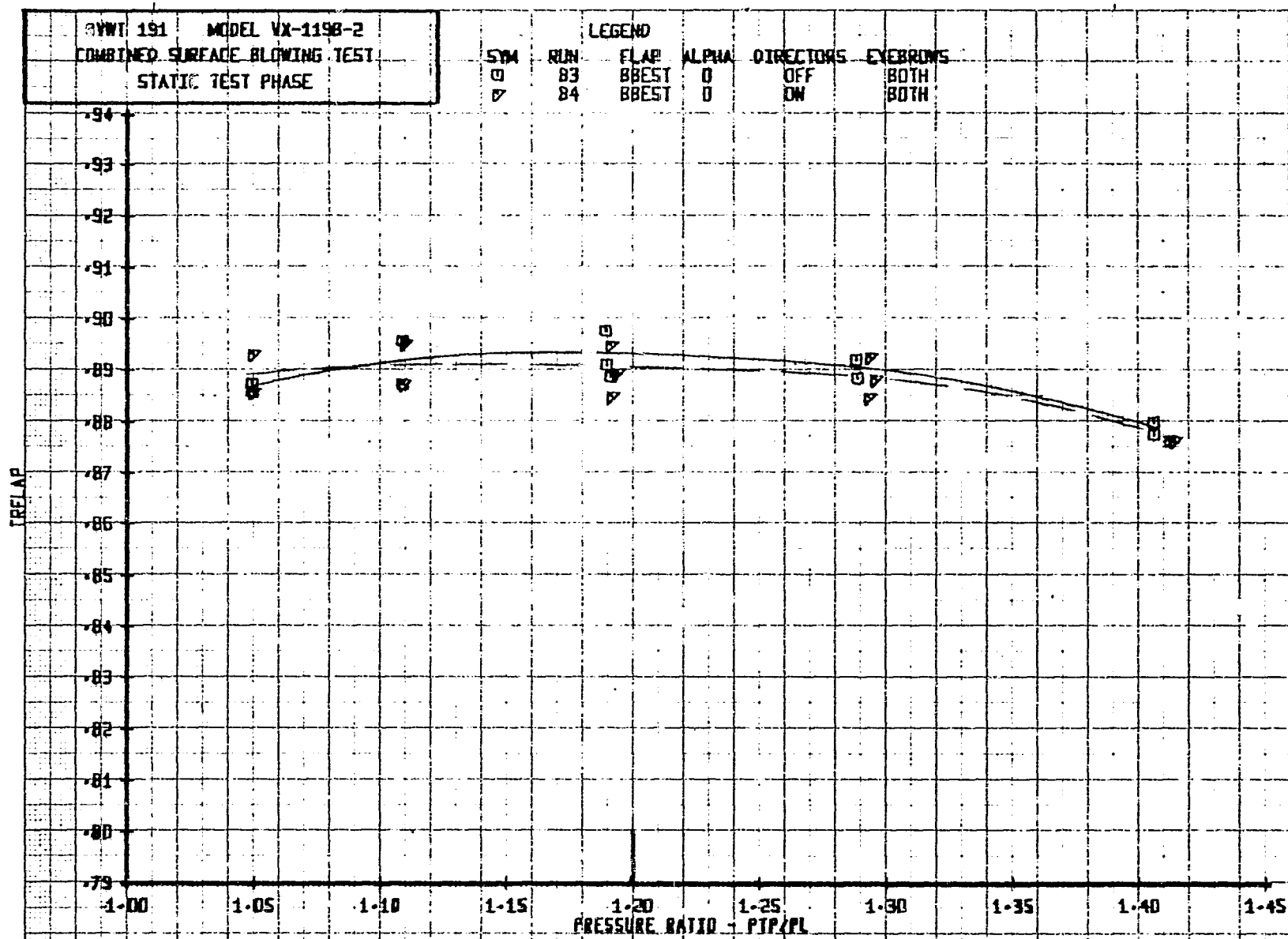


Figure 7.1-24. Flap B, Effect of Upper Flow Directors
 a. Thrust Recovery

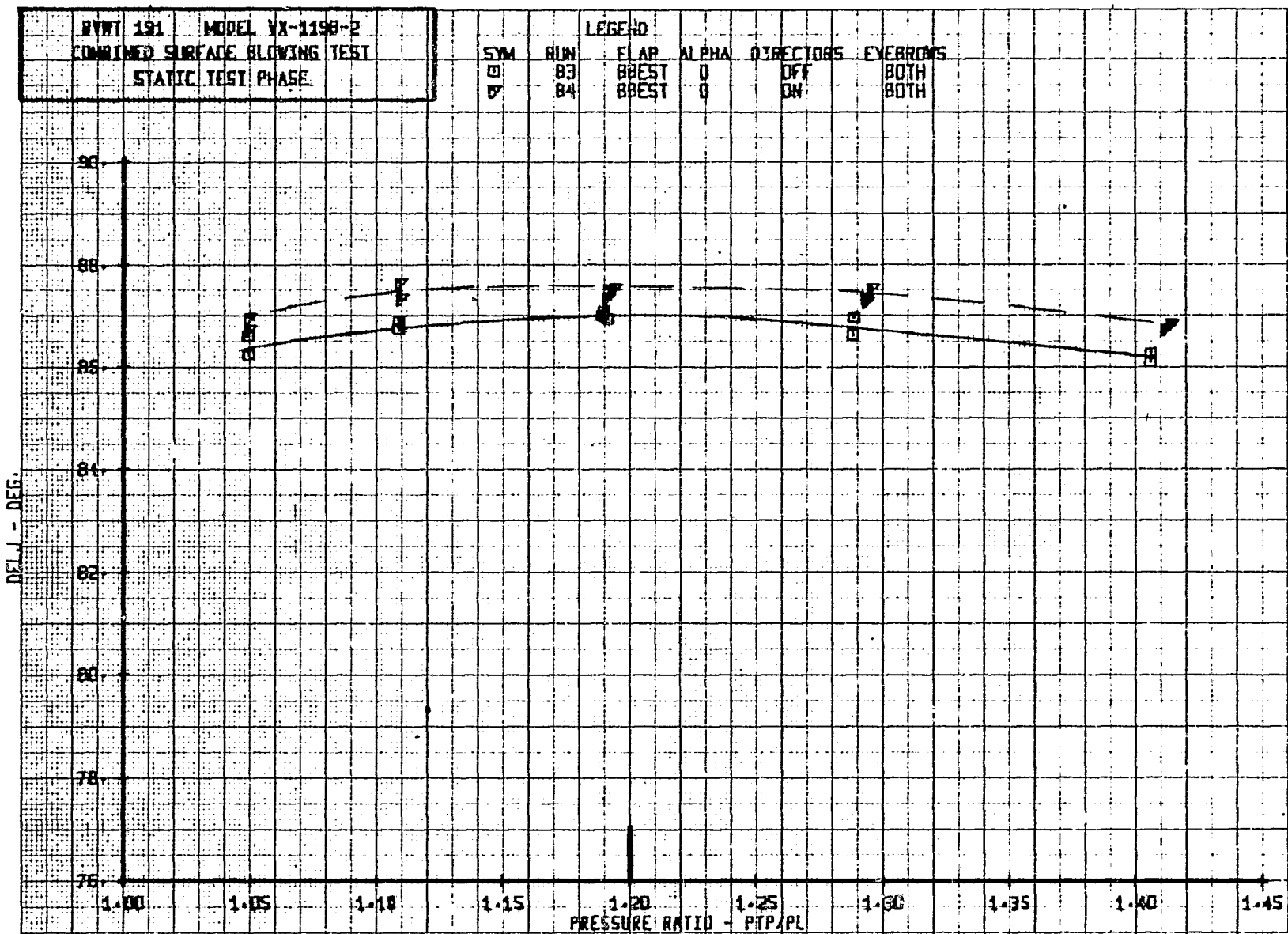


Figure 7.1-24. Flap B, Effect of Upper Flow Directors
b. Thrust-Deflection Angle

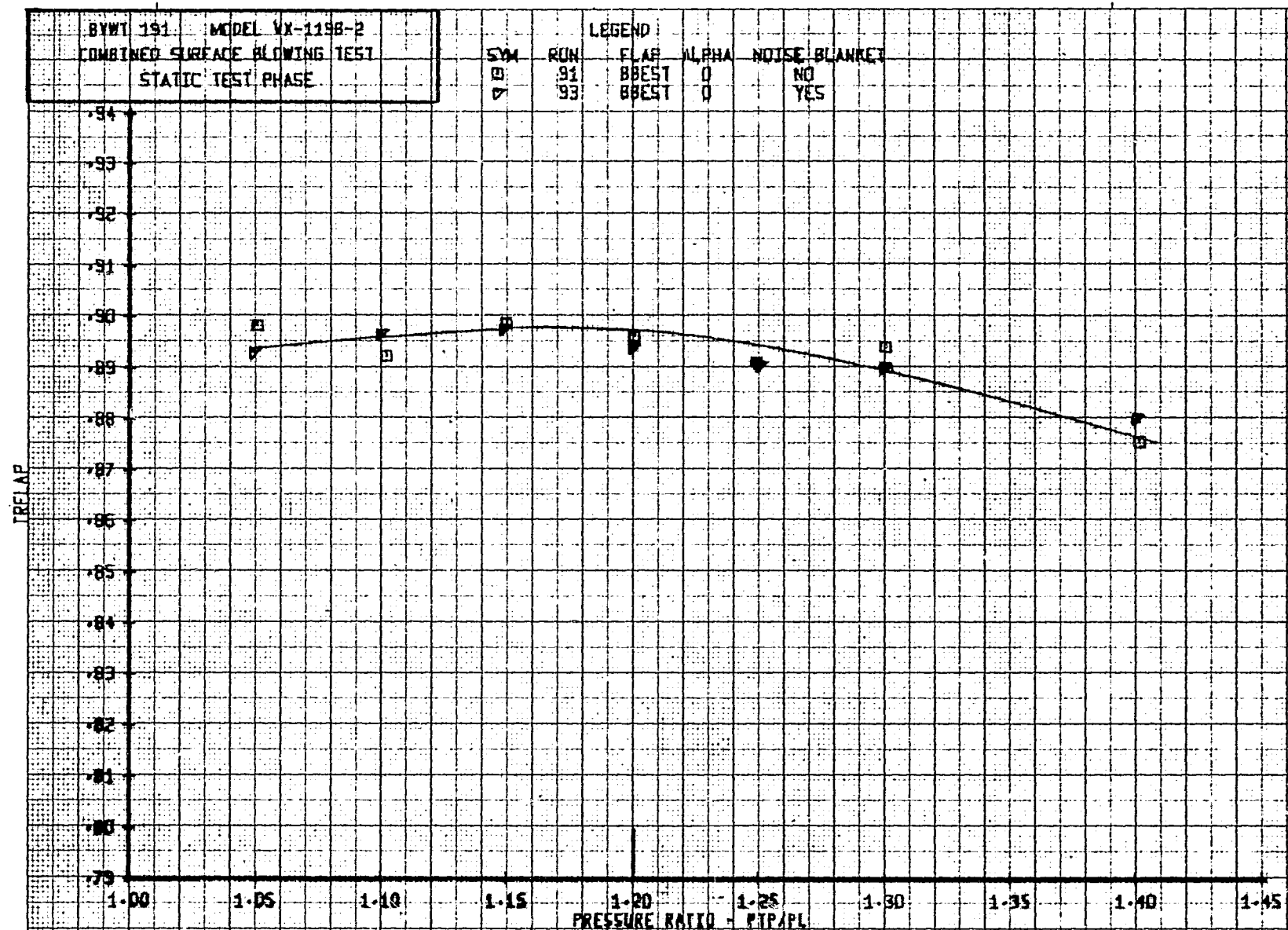


Figure 7.1-25. Data Repeatability
a. Thrust Recovery

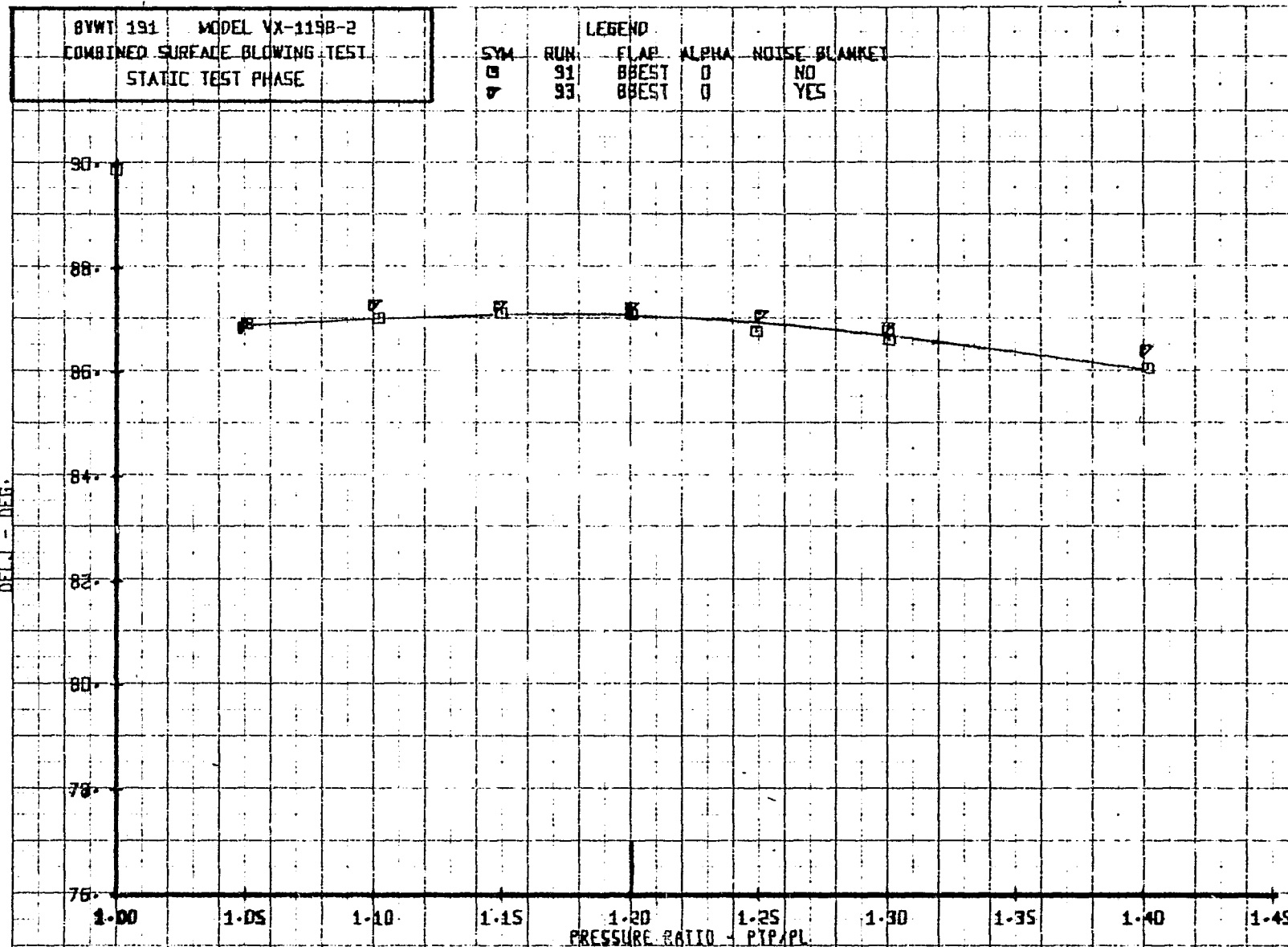


Figure 7.1-25. Data Repeatability
b. Thrust-Deflection Angle

LOWER EYEBROW ON
1.2 PRESSURE RATIO

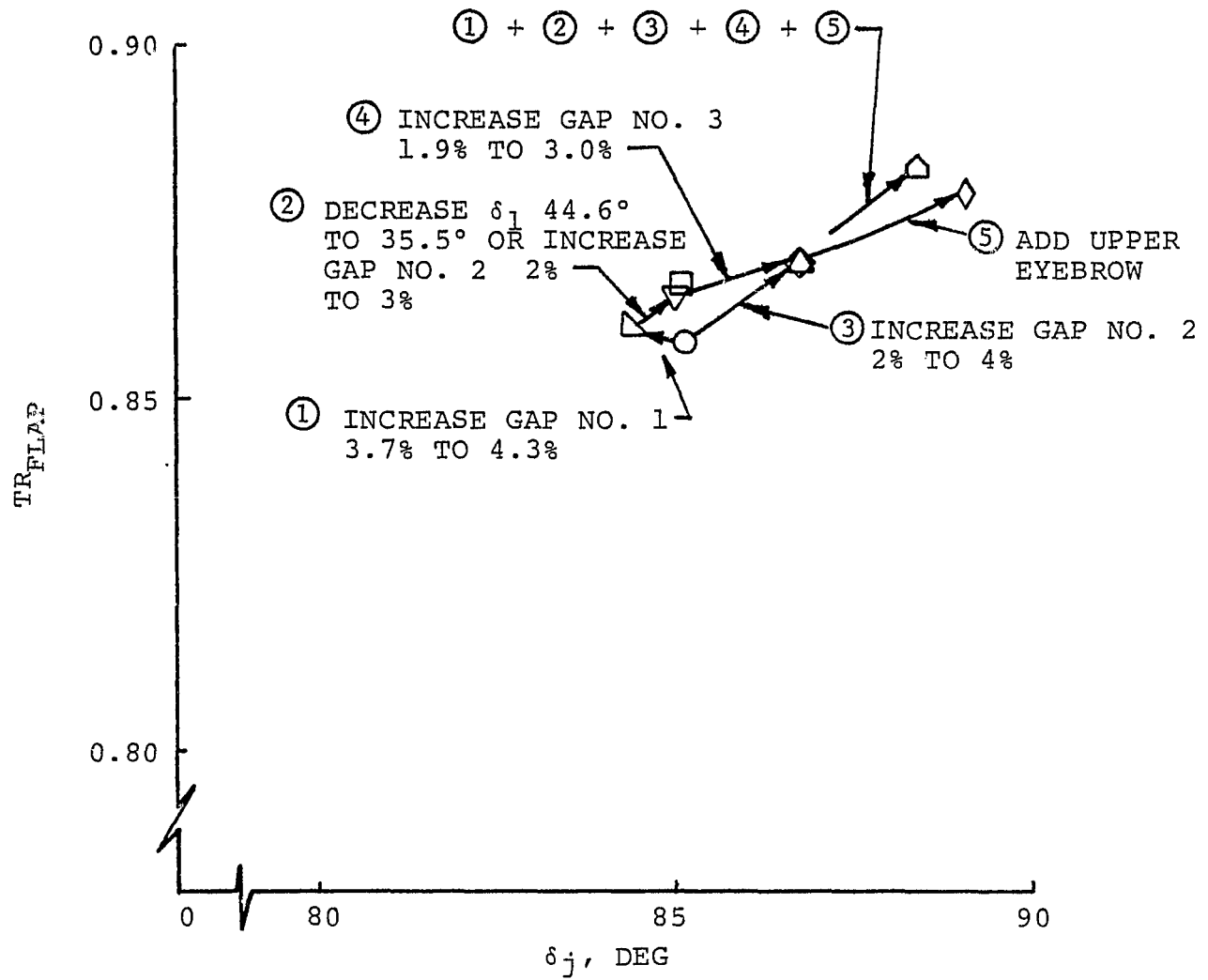


Figure 7.1-26. Improvement in Flap A Static Performance

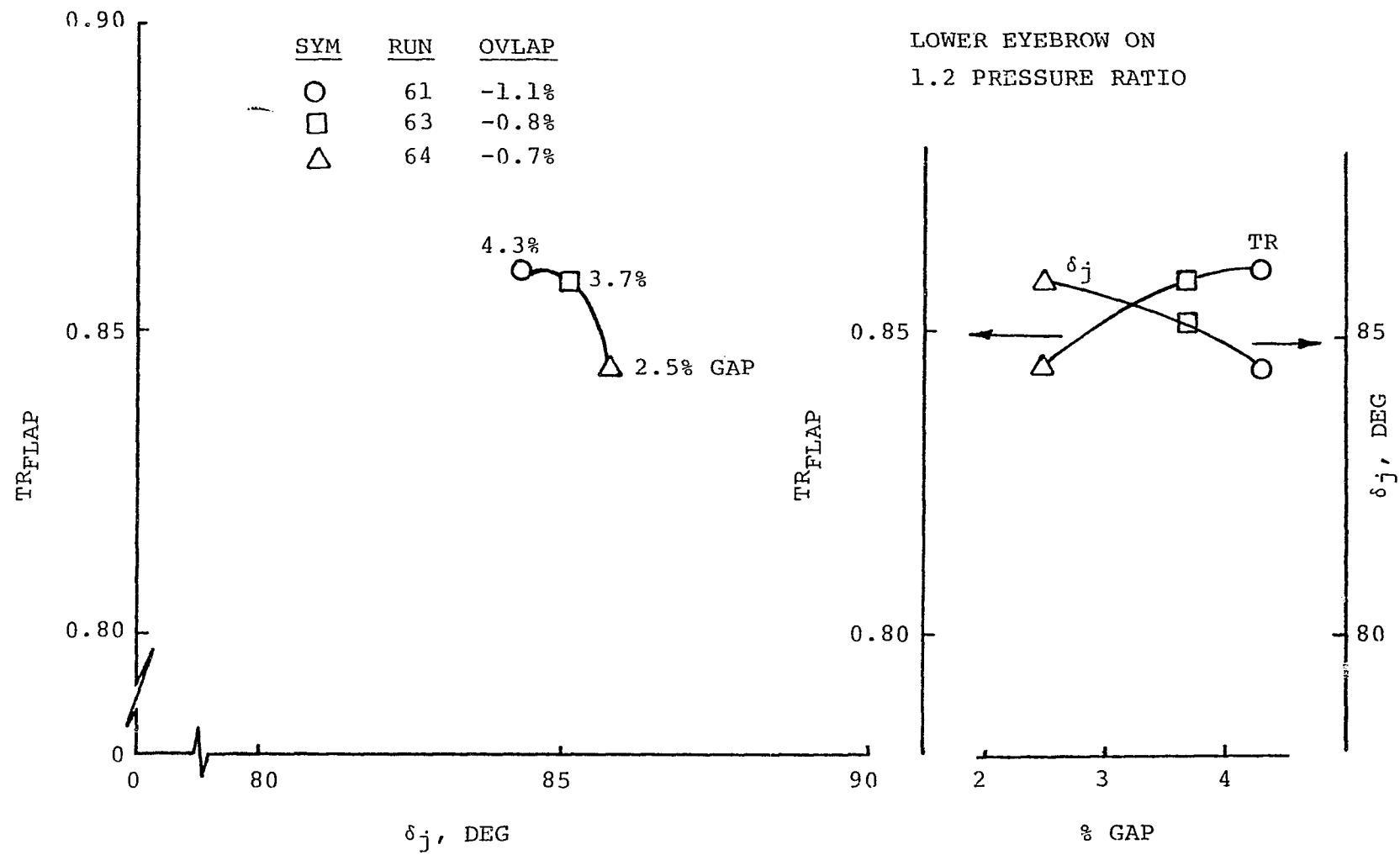


Figure 7.1-27. Flap A, Effect of Number 1 Gap

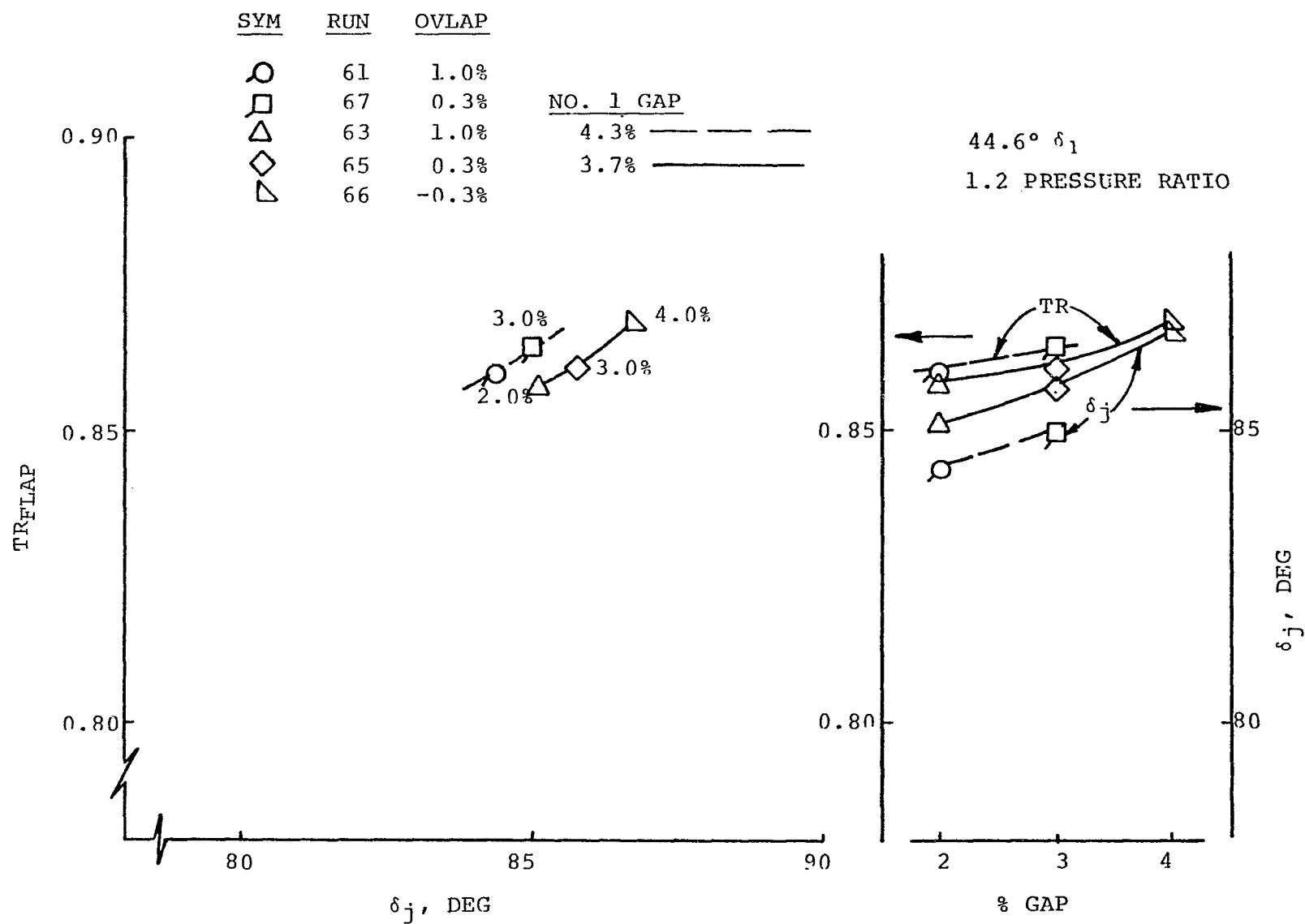


Figure 7.1-28. Flap A, Effect of Number 2 Gap

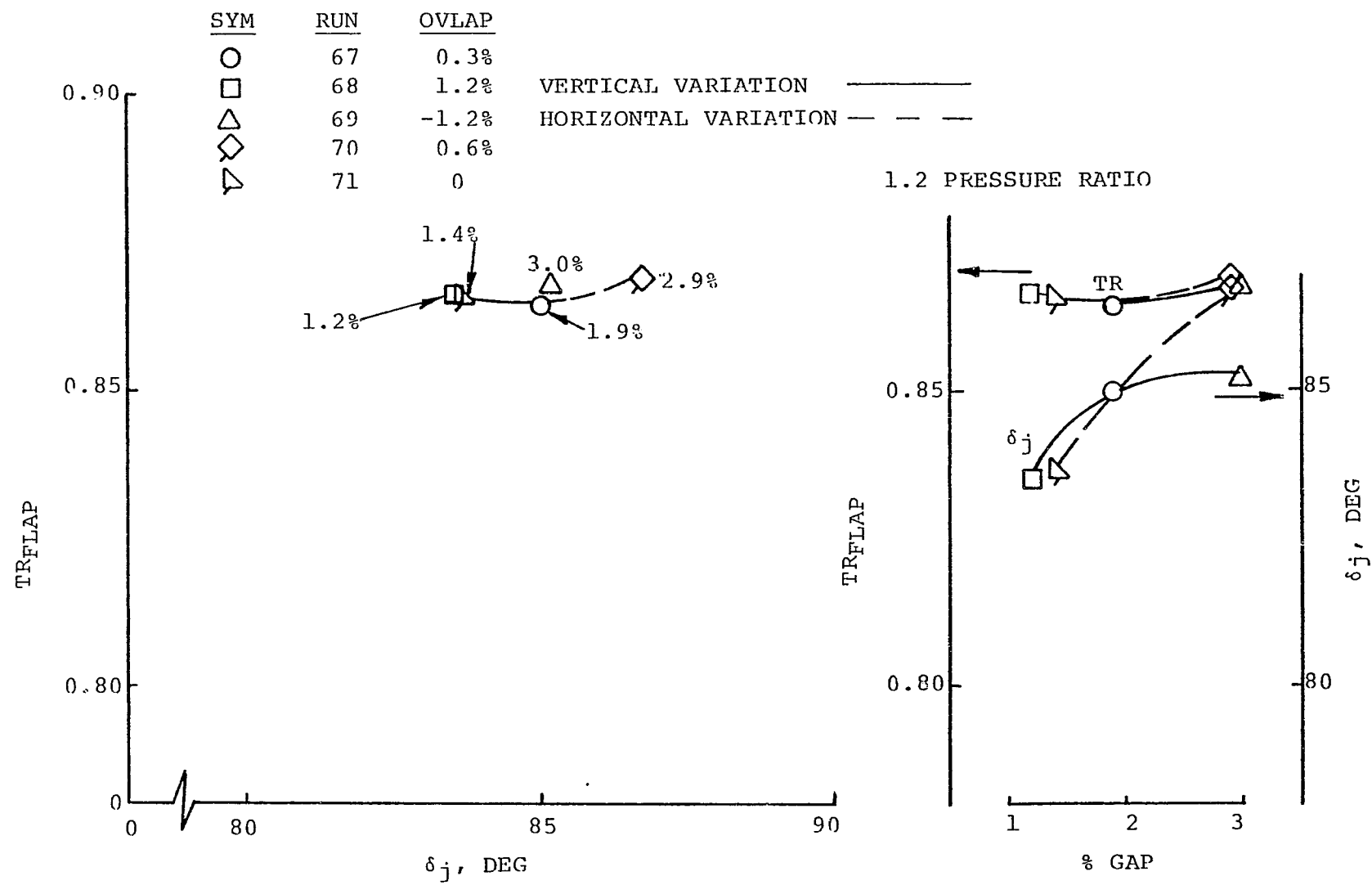
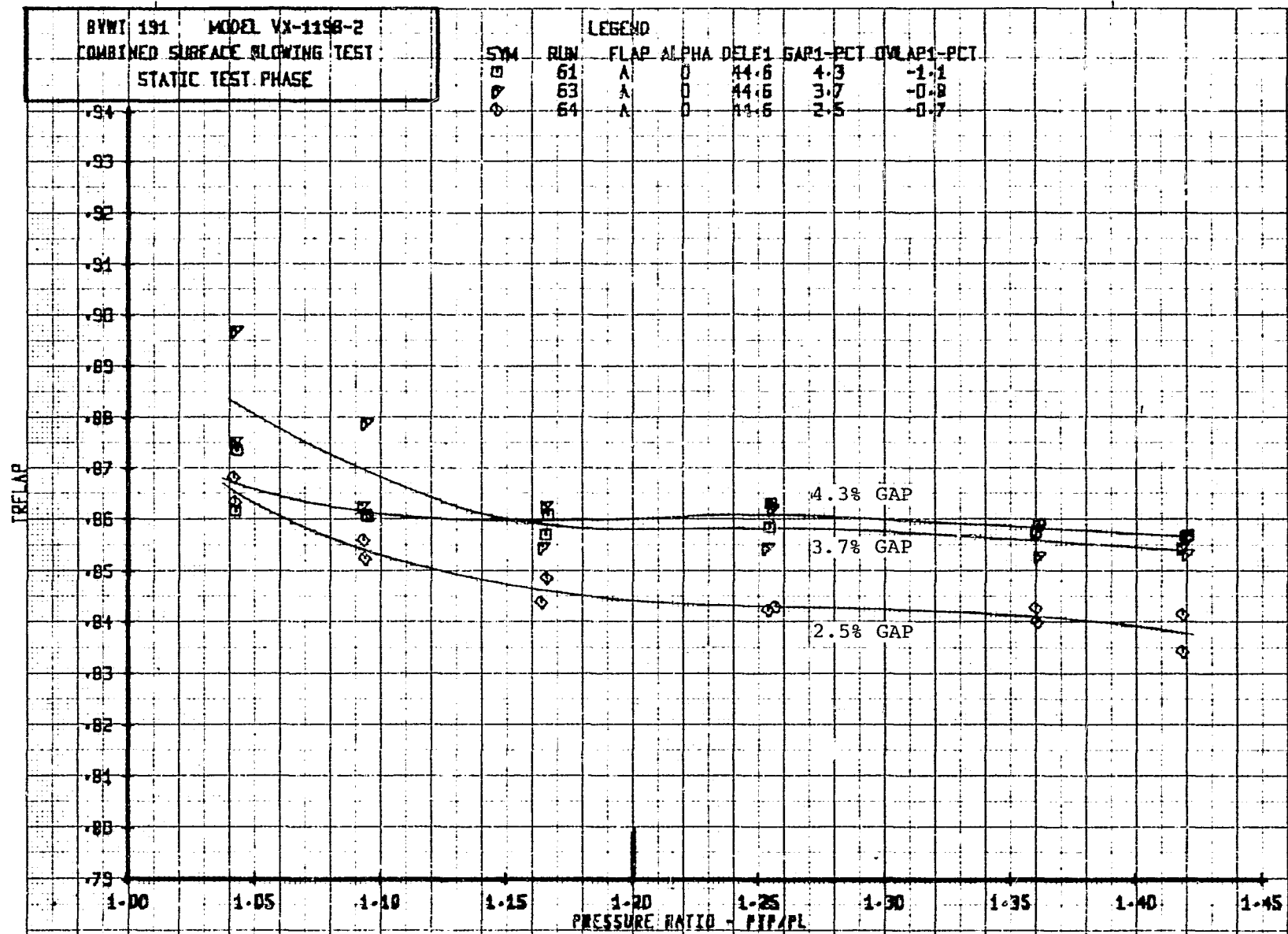


Figure 7.1-29. Flap A, Effect of Number 3 Gap



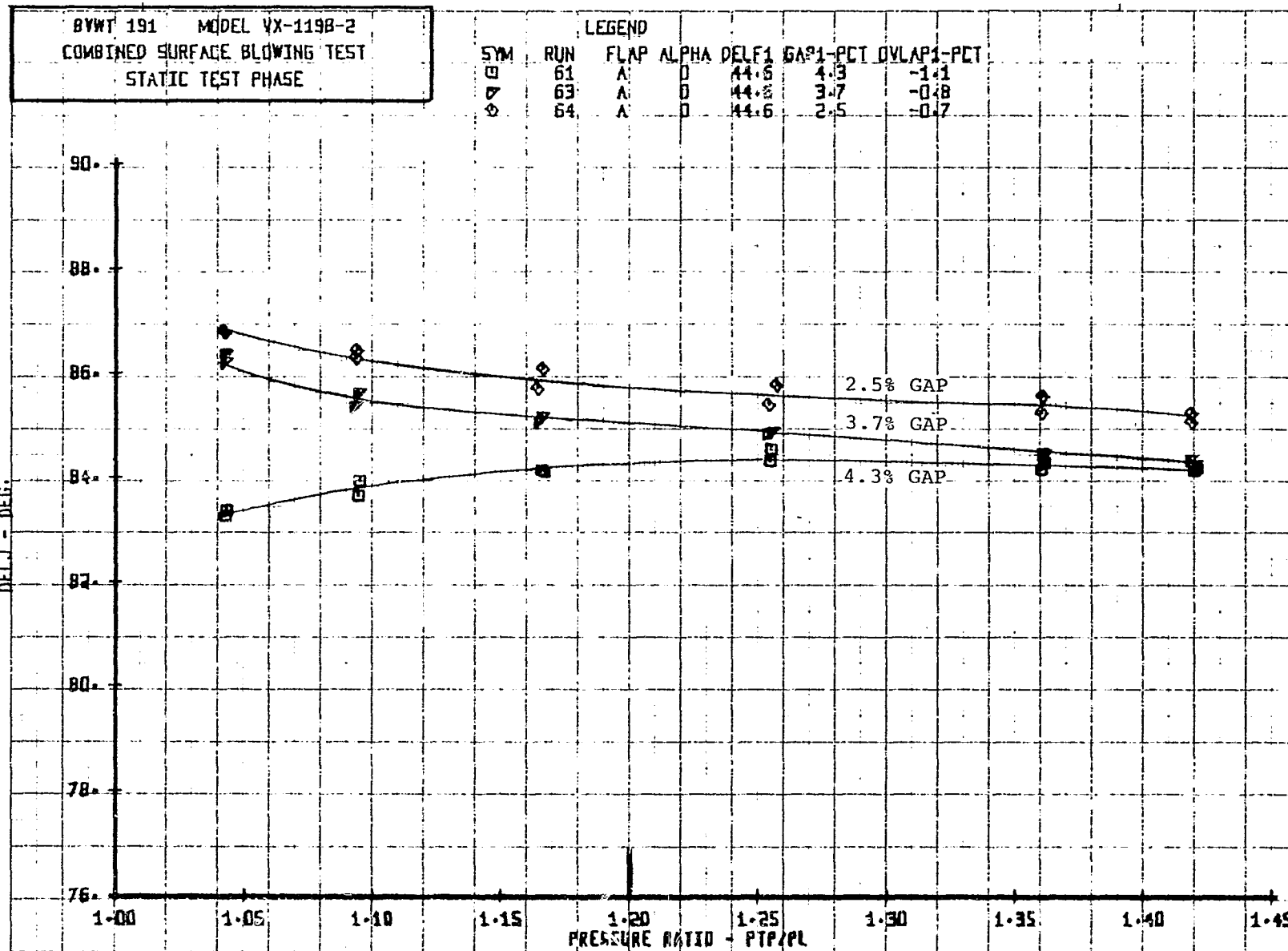


Figure 7.1-30. Flap A, First Slot Variation
b. Thrust-Deflection Angle

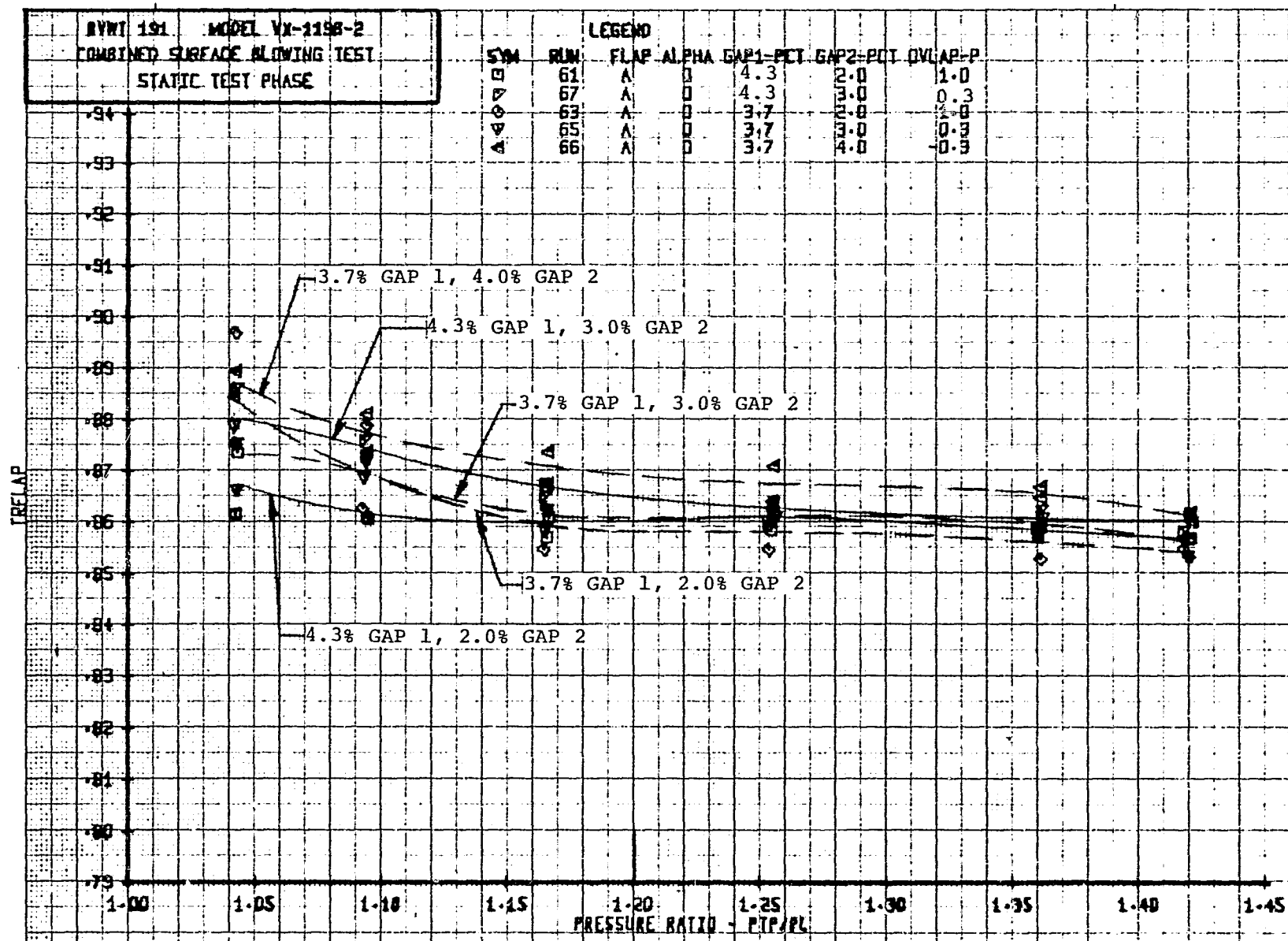


Figure 7.1-31. Flap A, Second Slot Variation
a. Thrust Recovery

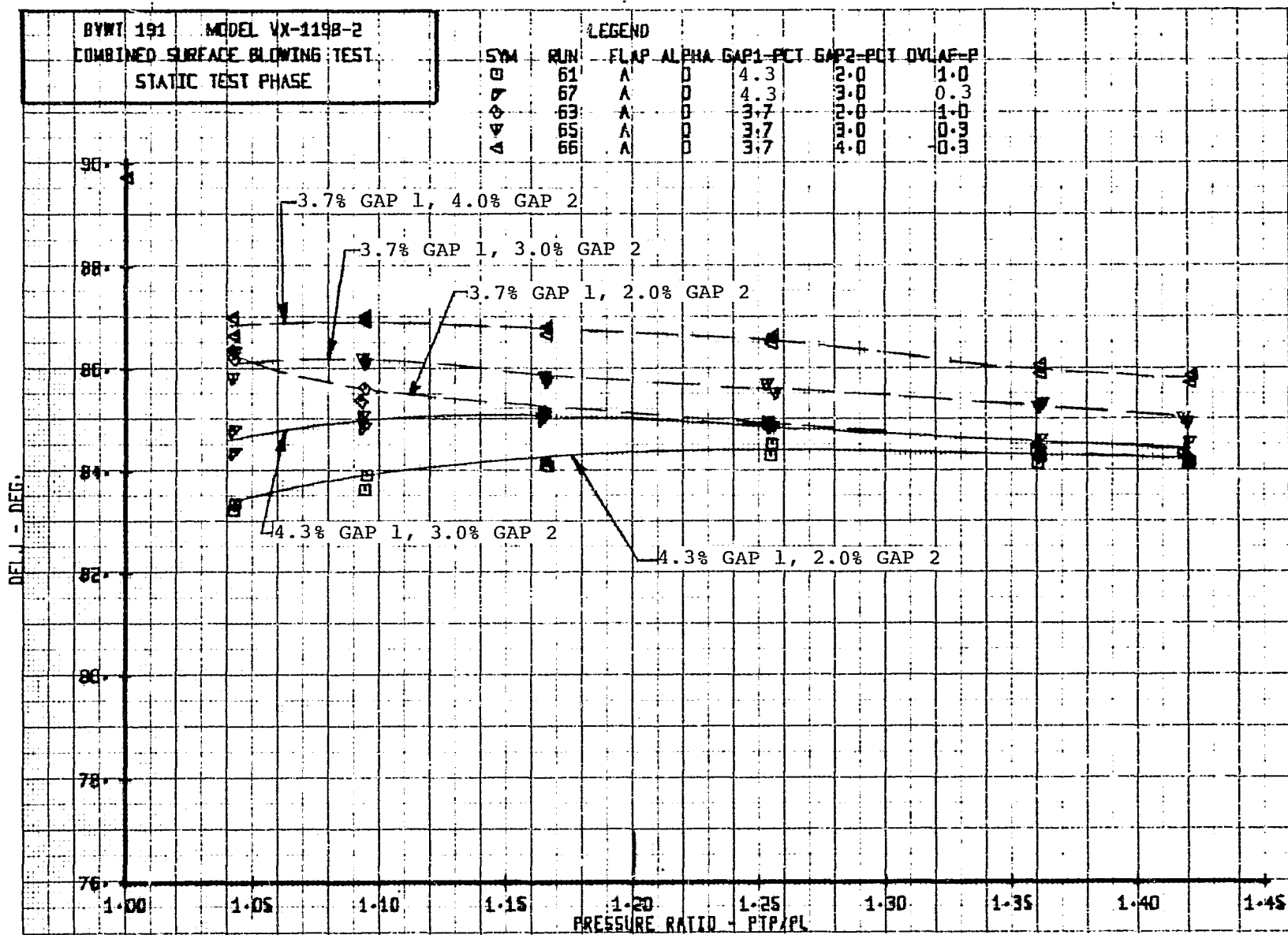


Figure 7.1-31. Flap A, Second Slot Variation

b. Thrust-Deflection Angle

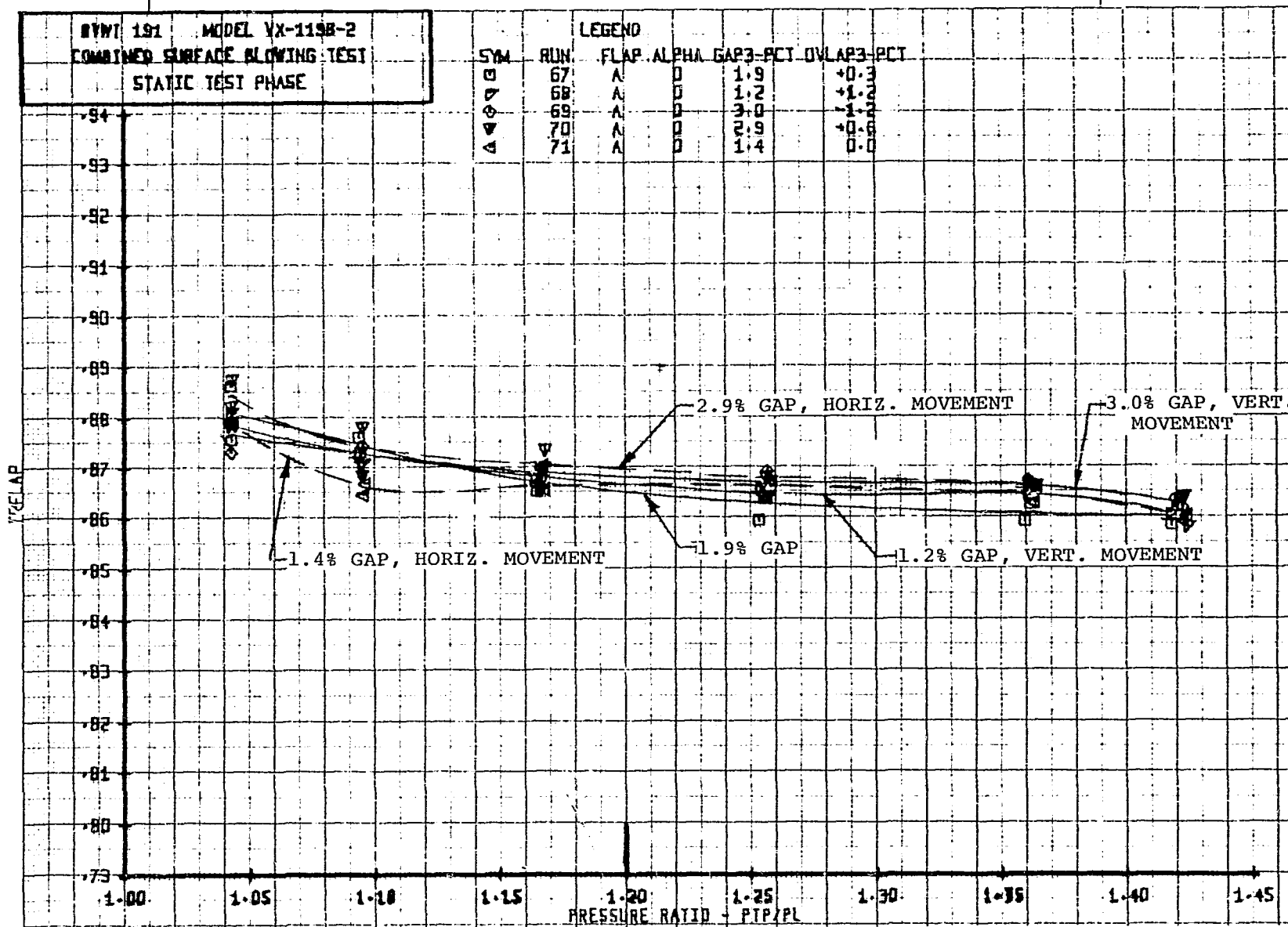


Figure 7.1-32. Flap A, Third Slot Variation
a. Thrust Recovery

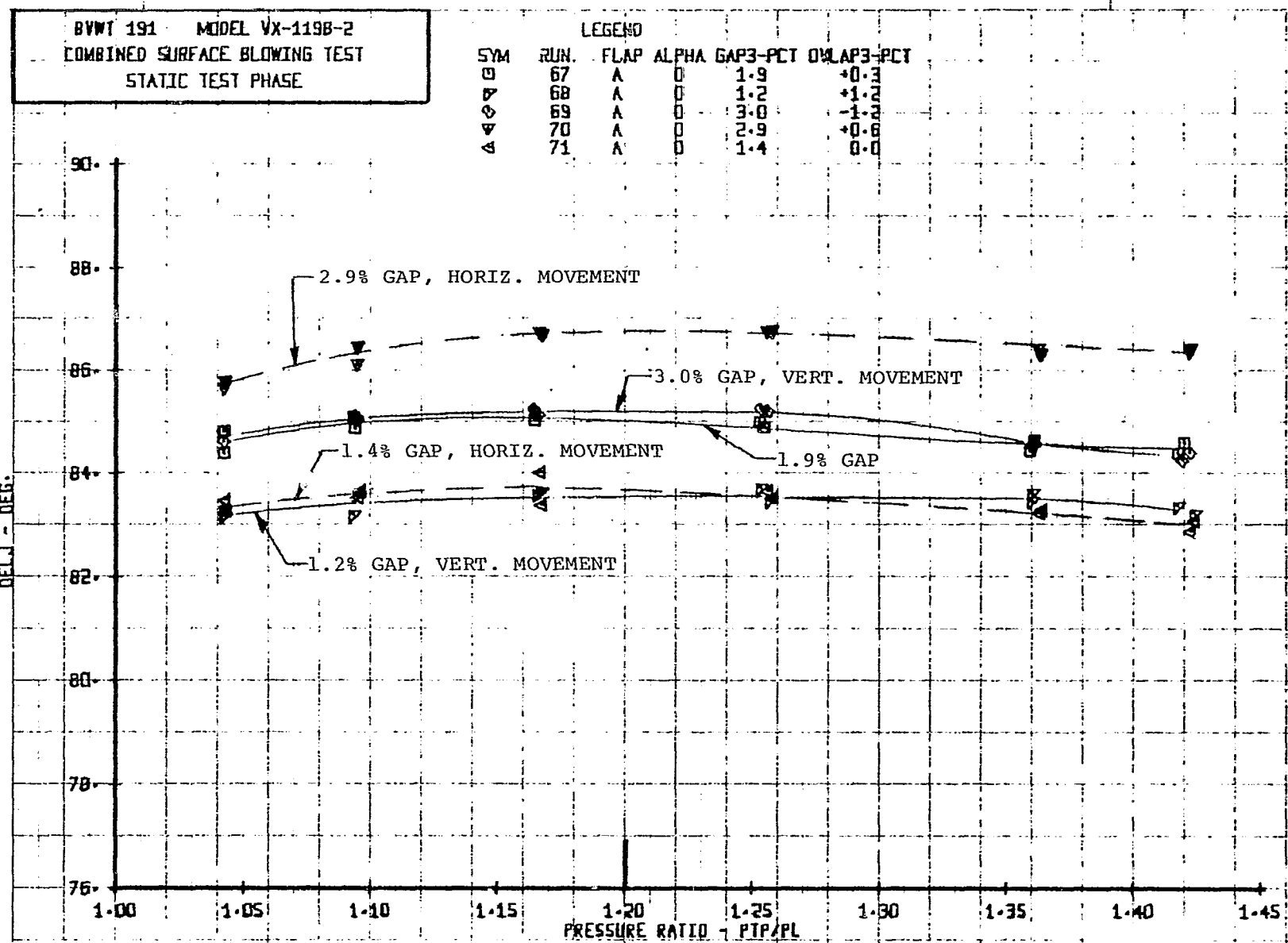


Figure 7.1-32. Flap A, Third Slot Variation
 b. Thrust-Deflection Angle

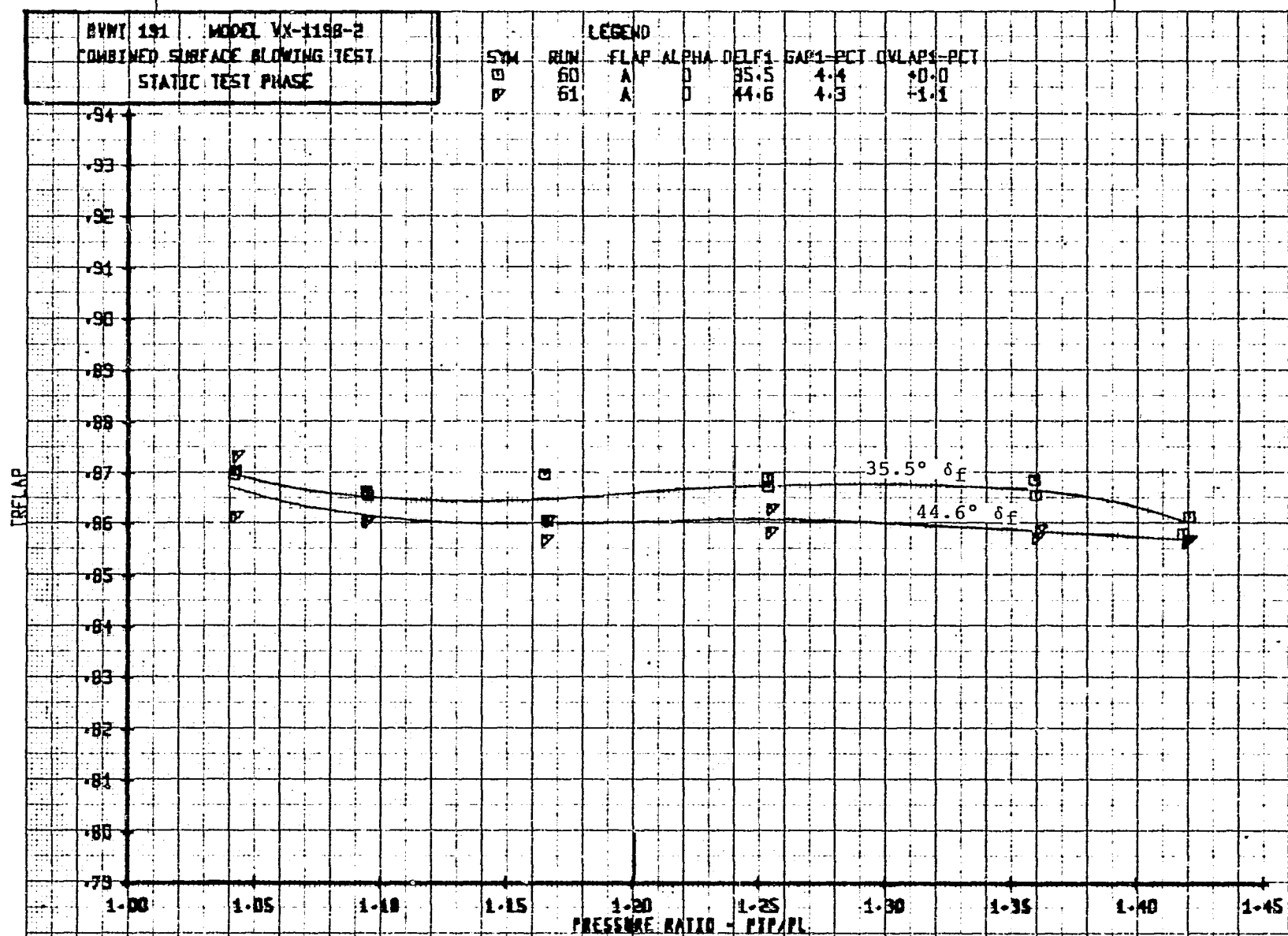


Figure 7.1-33. Flap A, First Flap Angle Change
a. Thrust Recovery

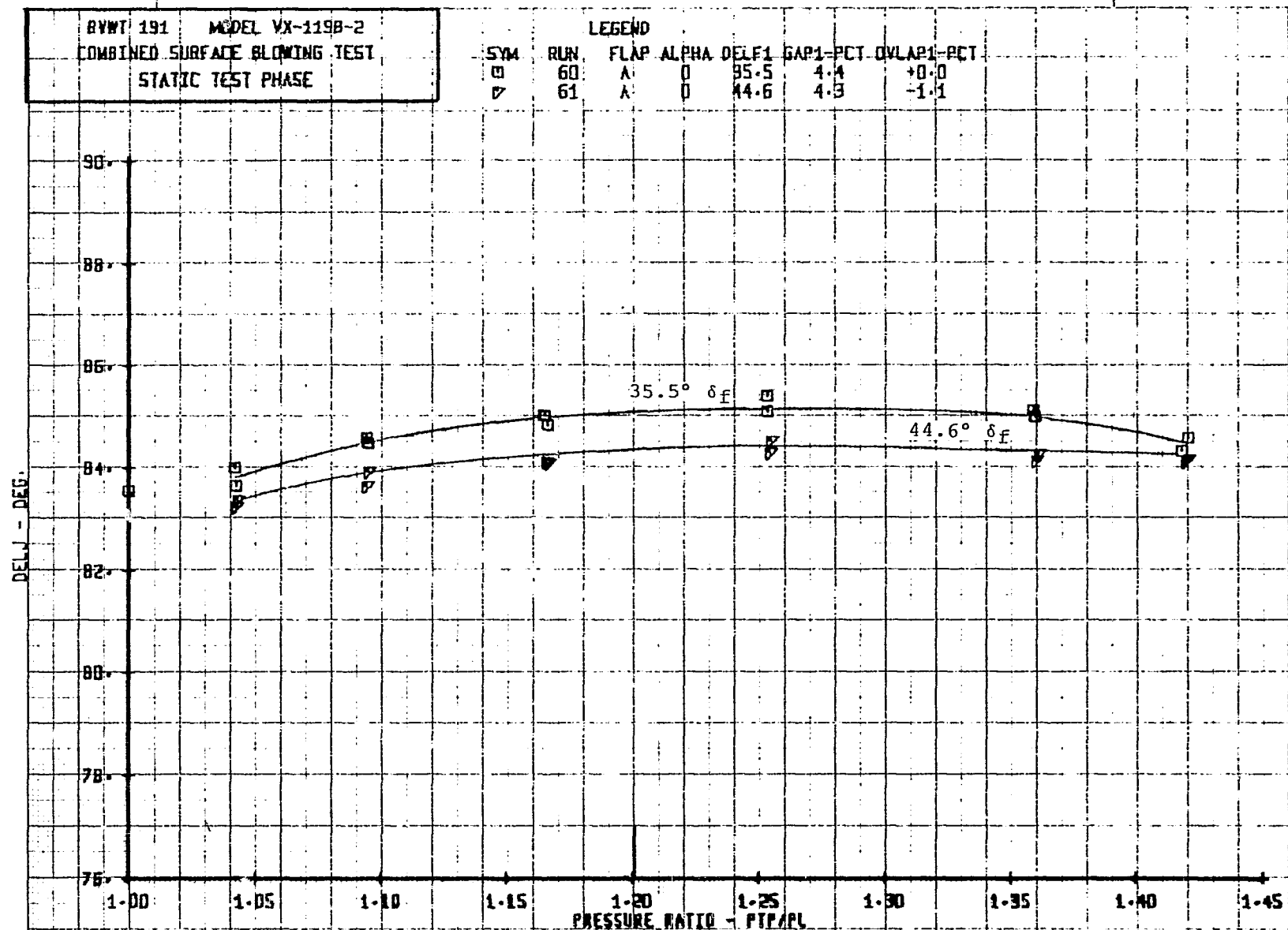


Figure 7.1-33. Flap A, First Flap Angle Change
b. Thrust-Deflection Angle

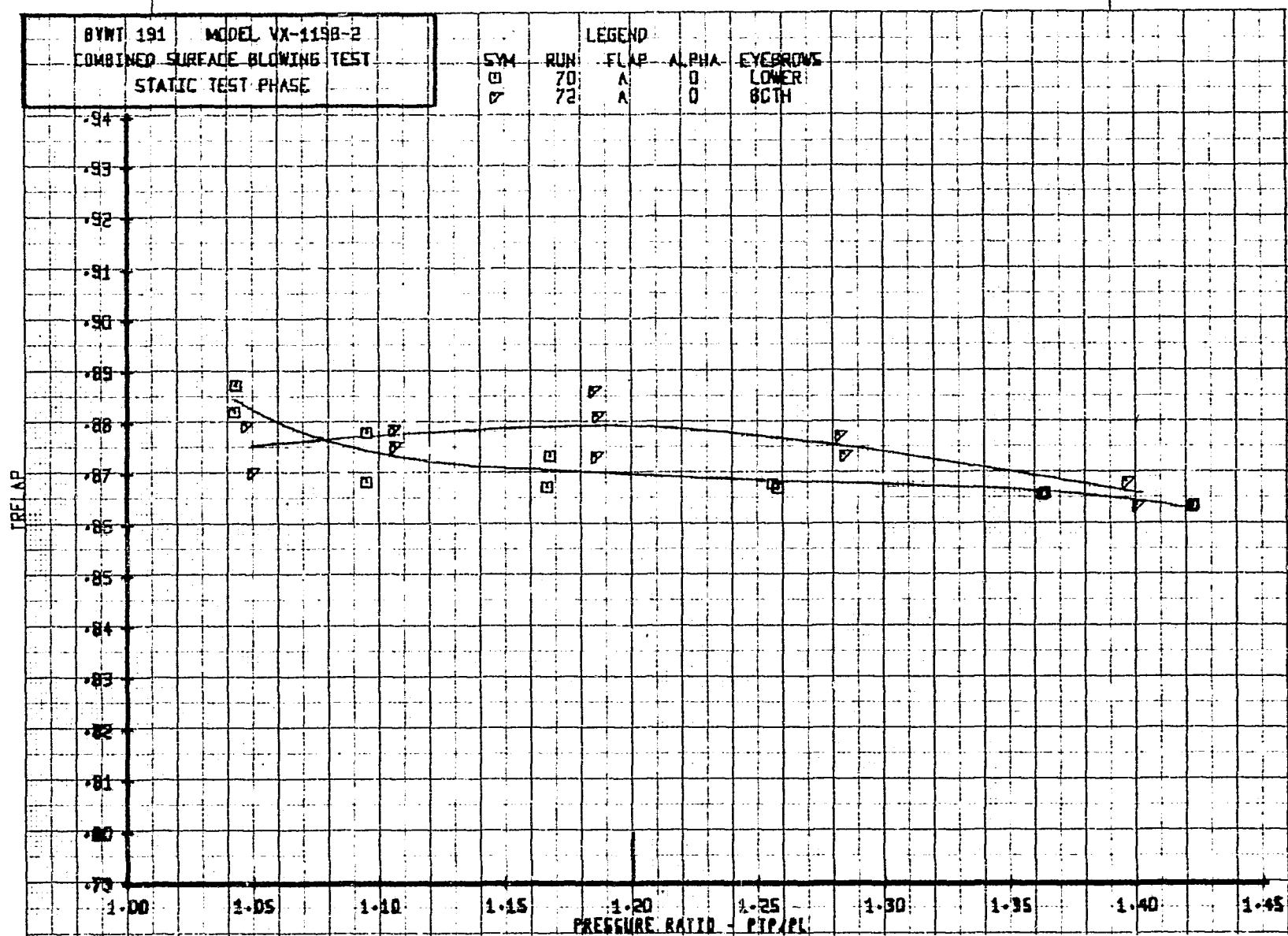


Figure 7.1-34. Flap A, Effect of Upper Eyebrows
a. Thrust Recovery

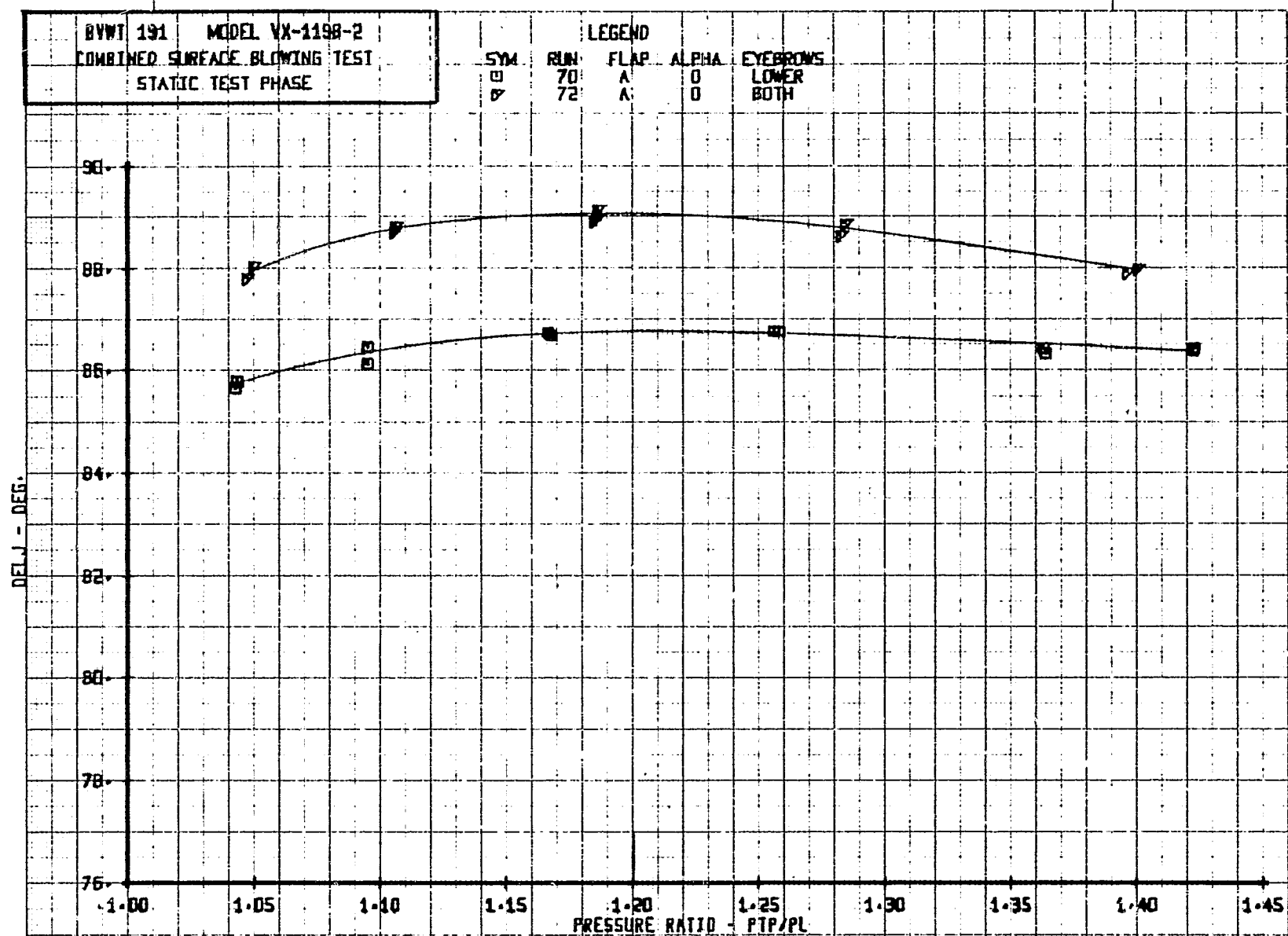


Figure 7.1-34. Flap A, Effect of Upper Eyebrows
b. Thrust-Deflection Angle

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

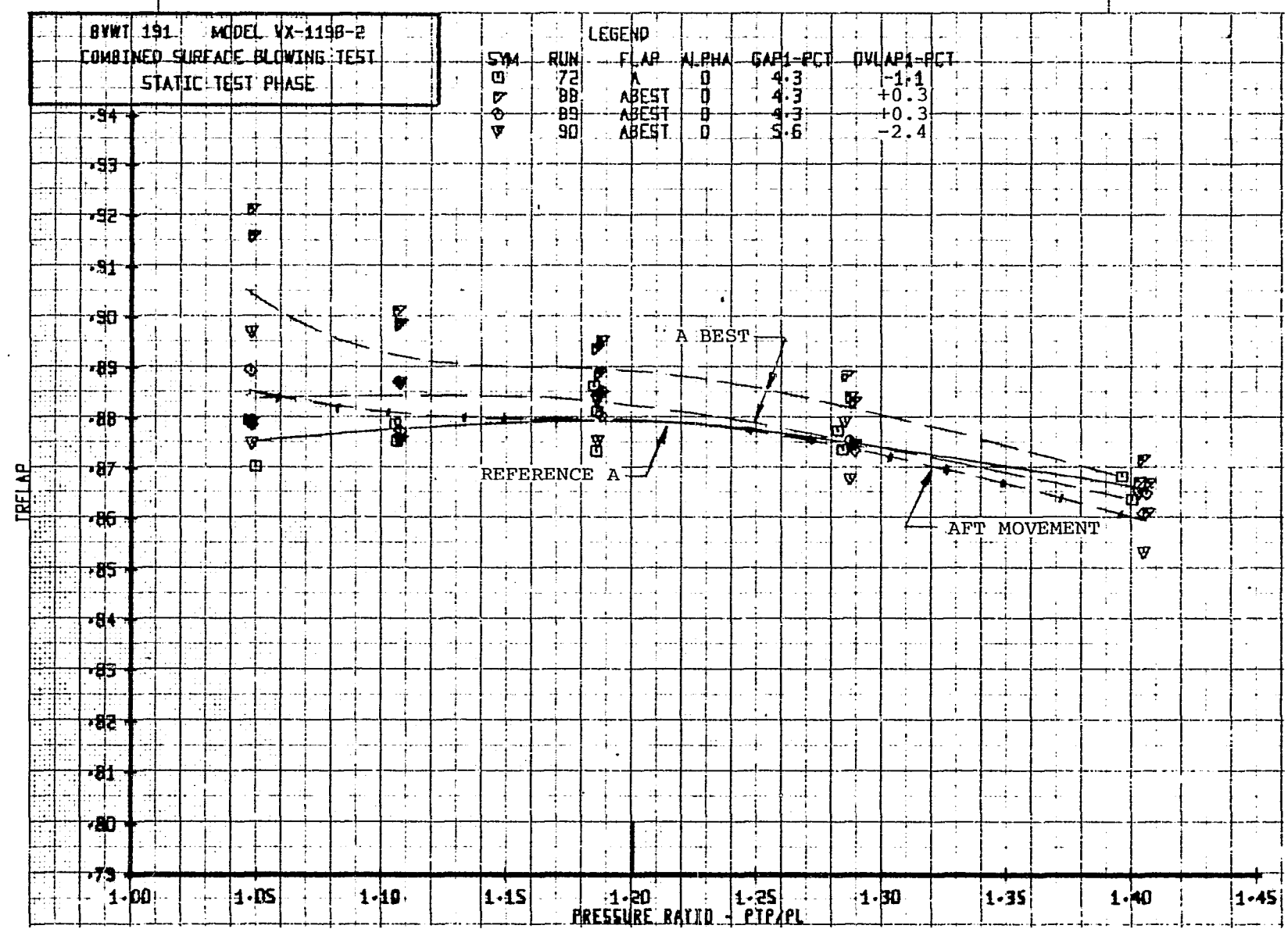


Figure 7.1-35. Best Flap A and Aft Flap Movement
a. Thrust Recovery

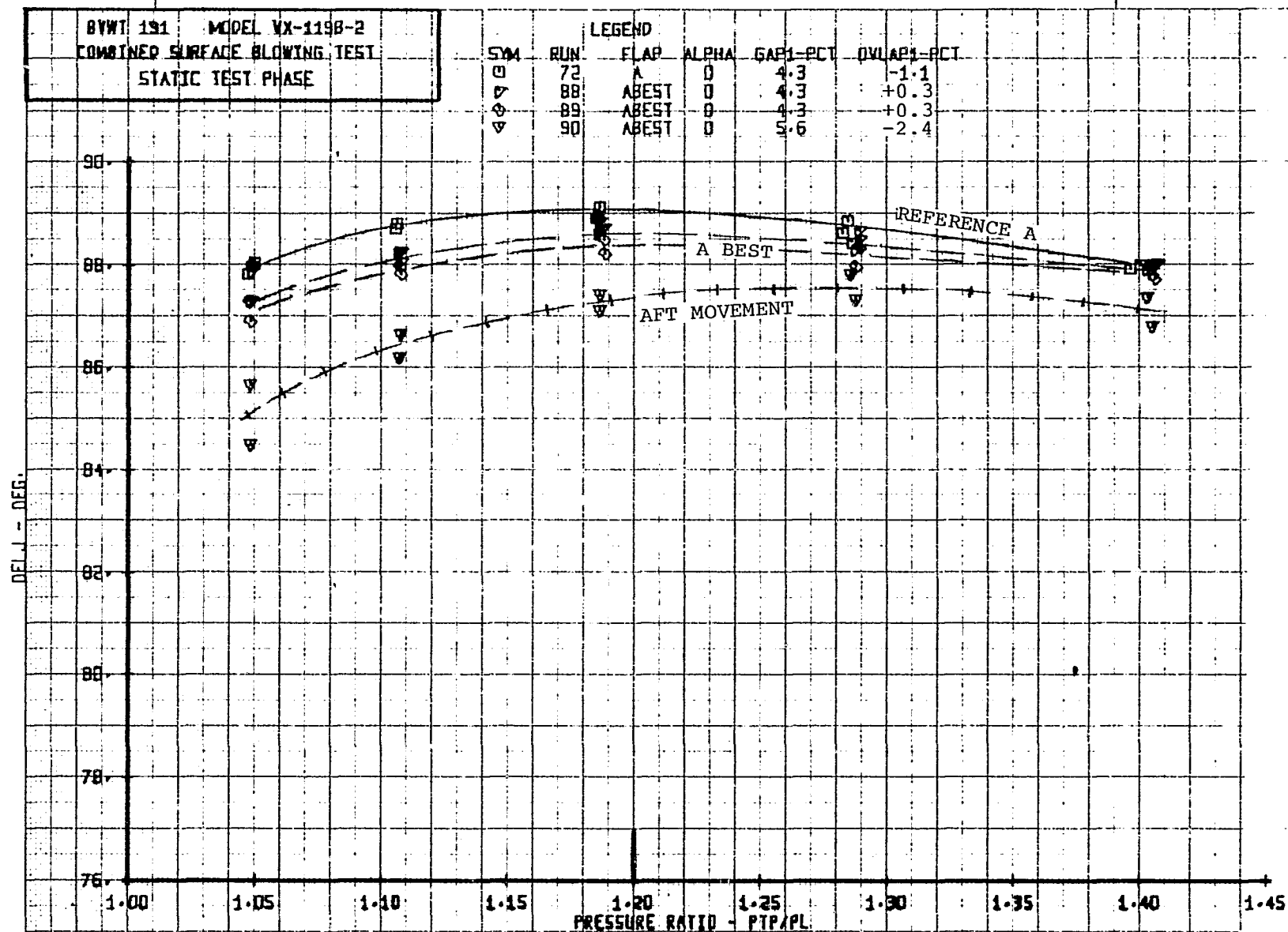


Figure 7.1-35. Best Flap A and Aft Flap Movement

b. Thrust-Deflection Angle

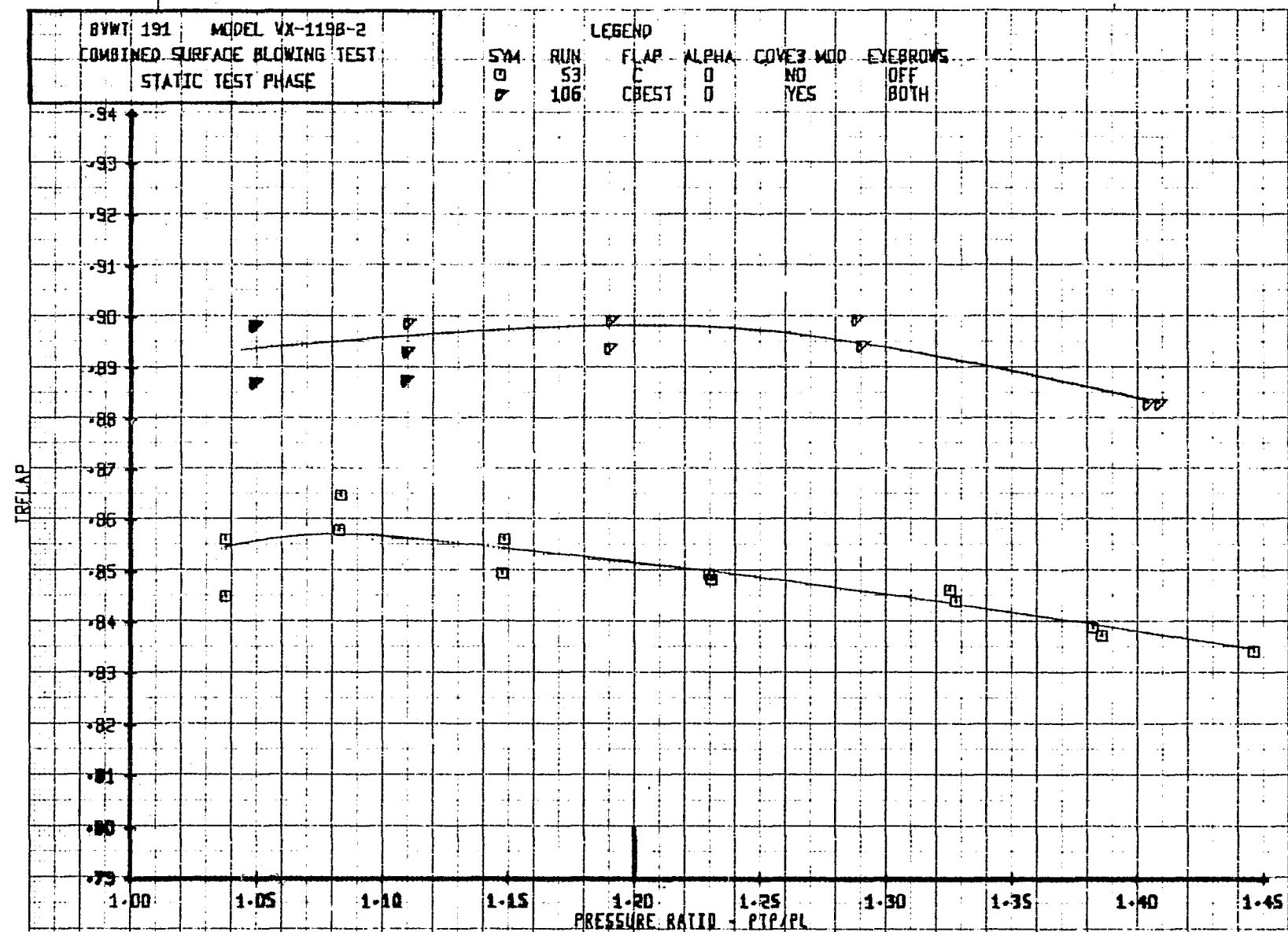


Figure 7.1-36. Best Flap C with Both Eyebrows

a. Thrust Recovery

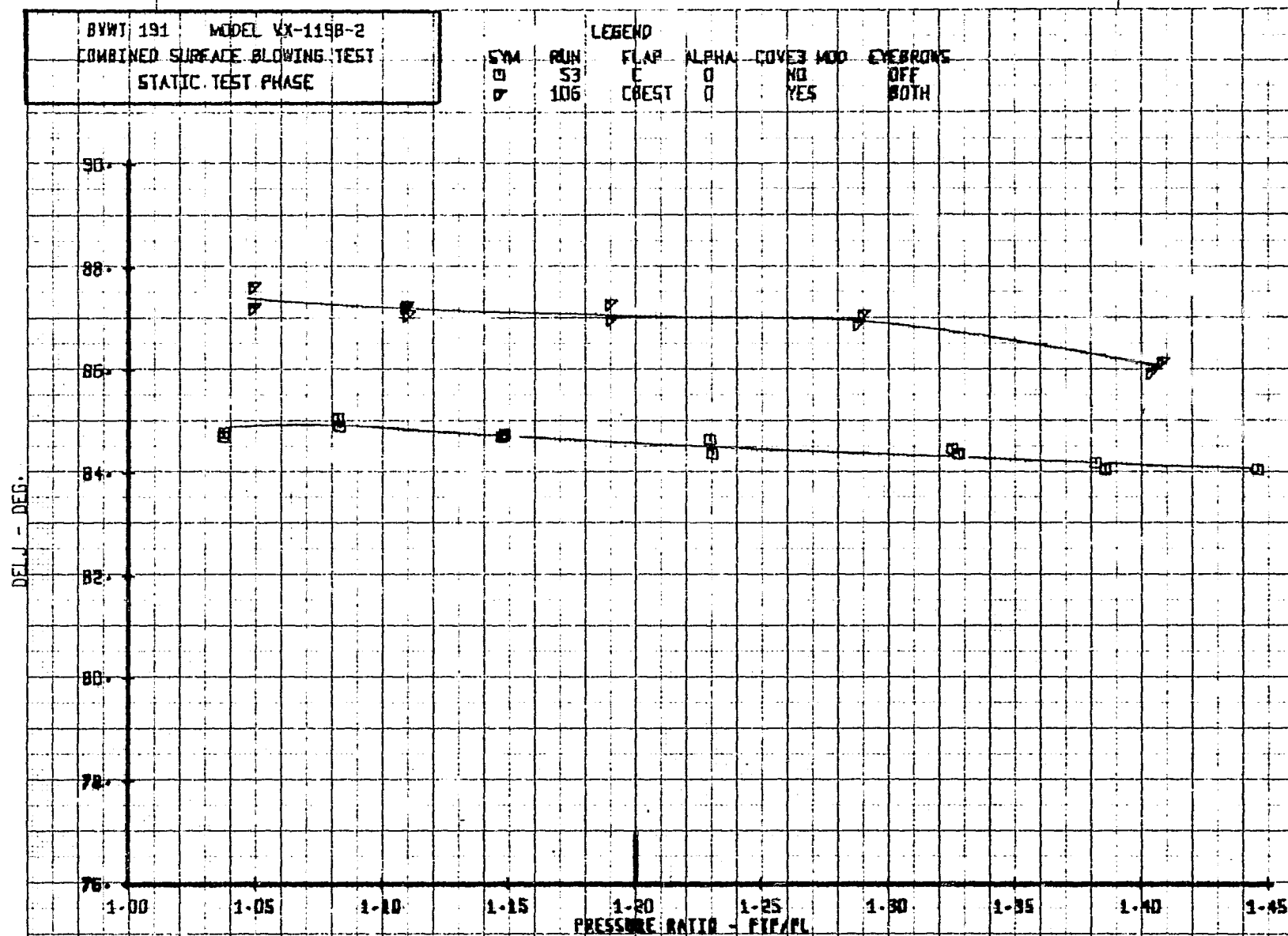


Figure 7.1-36. Best Flap C with Both Eyebrows

b. Thrust-Deflection Angle

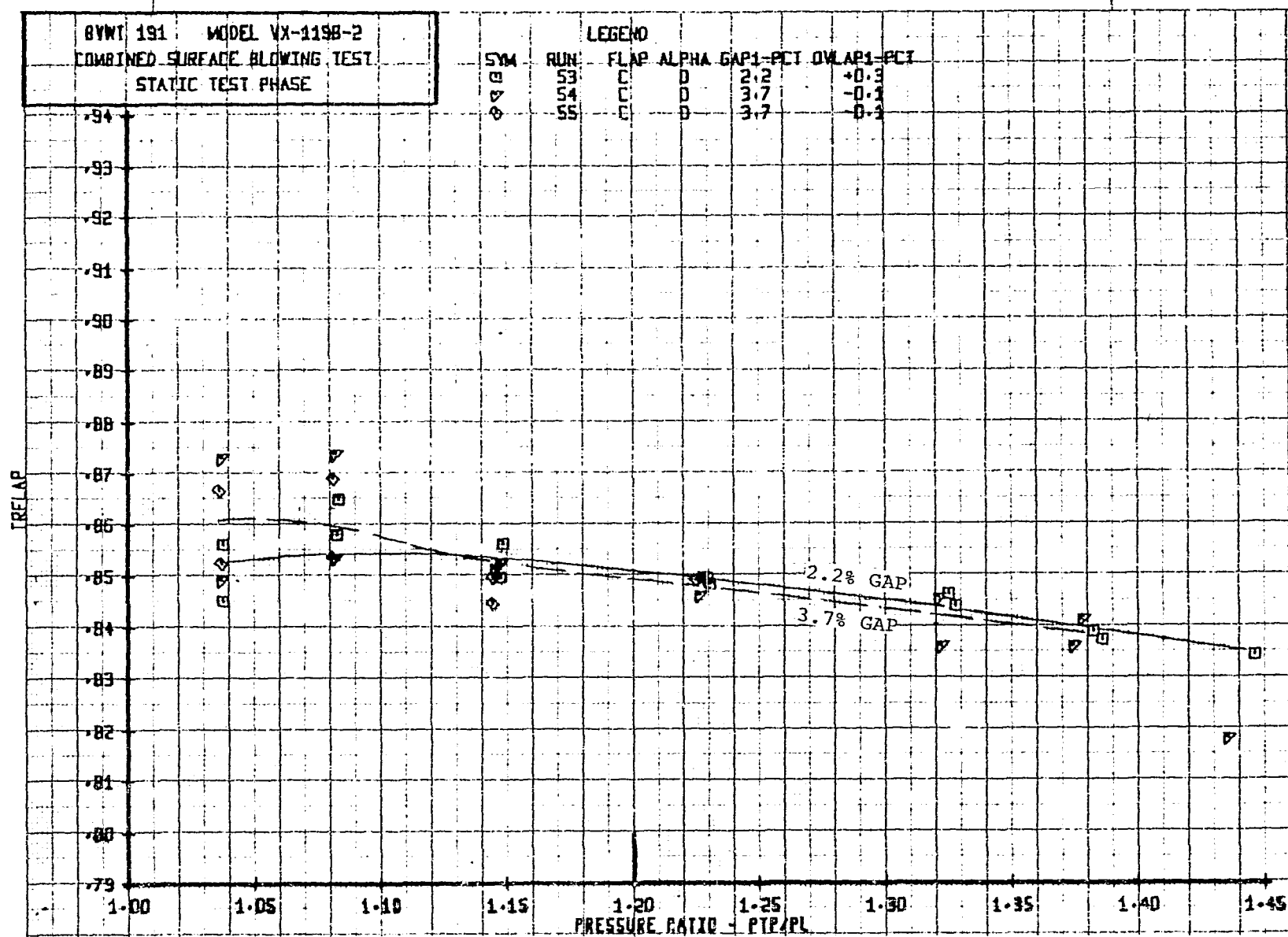


Figure 7.1-37. Flap C, First Slot Variation
a. Thrust Recovery

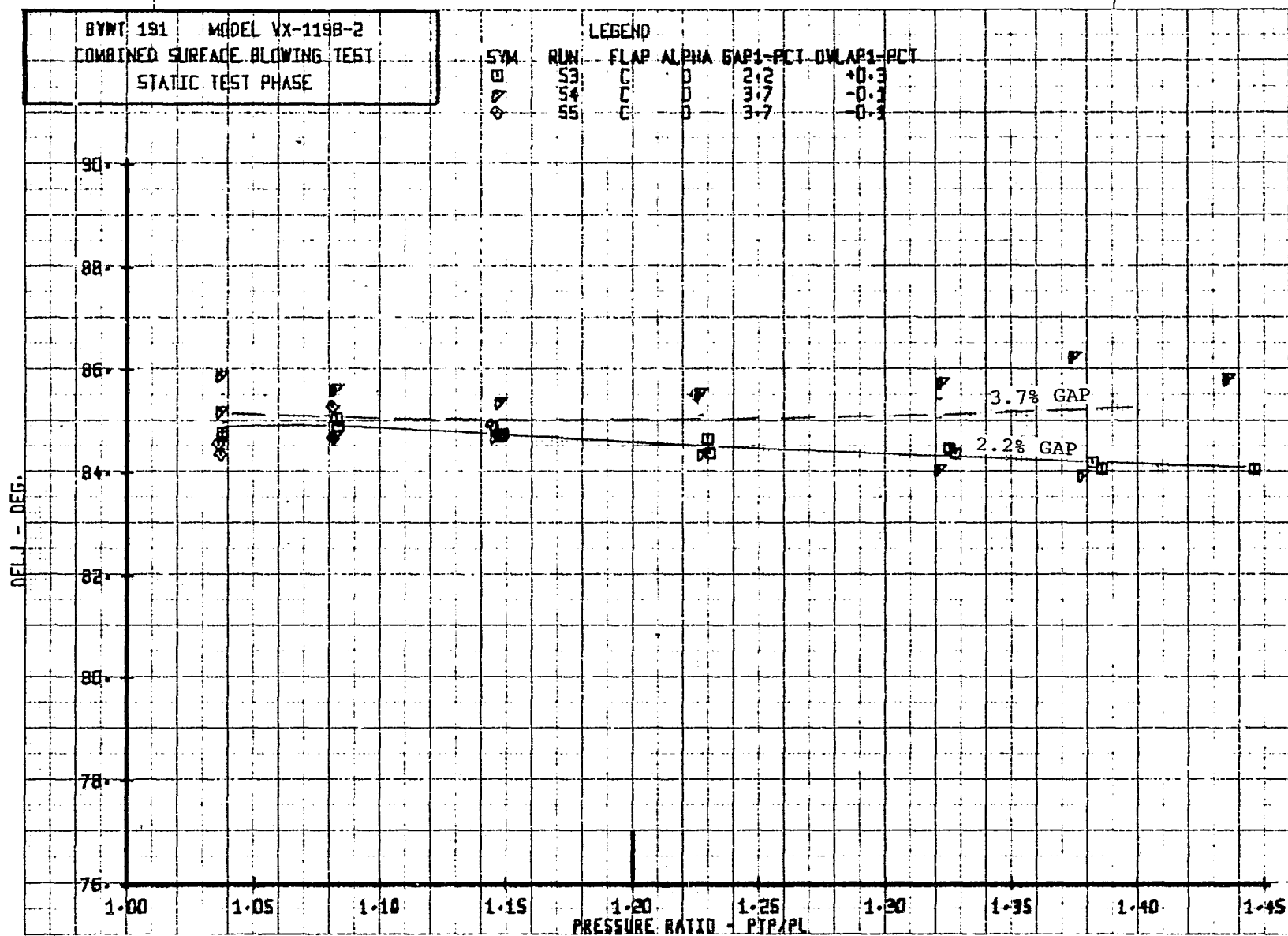


Figure 7.1-37. Flap C, First Slot Variation

b. Thrust-Deflection Angle

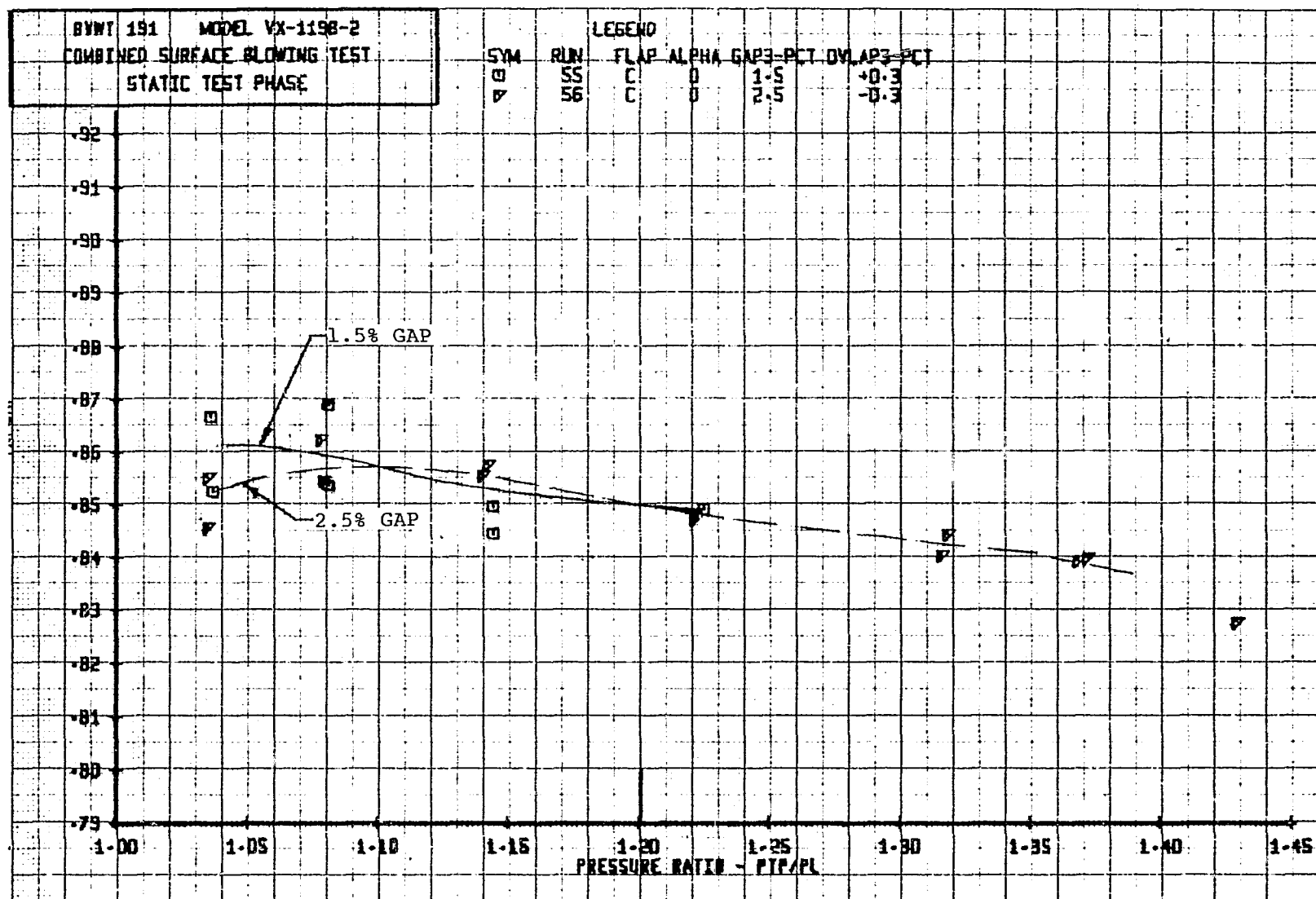


Figure 7.1-38. Flap C, Third Slot Variation
a. Thrust Recovery

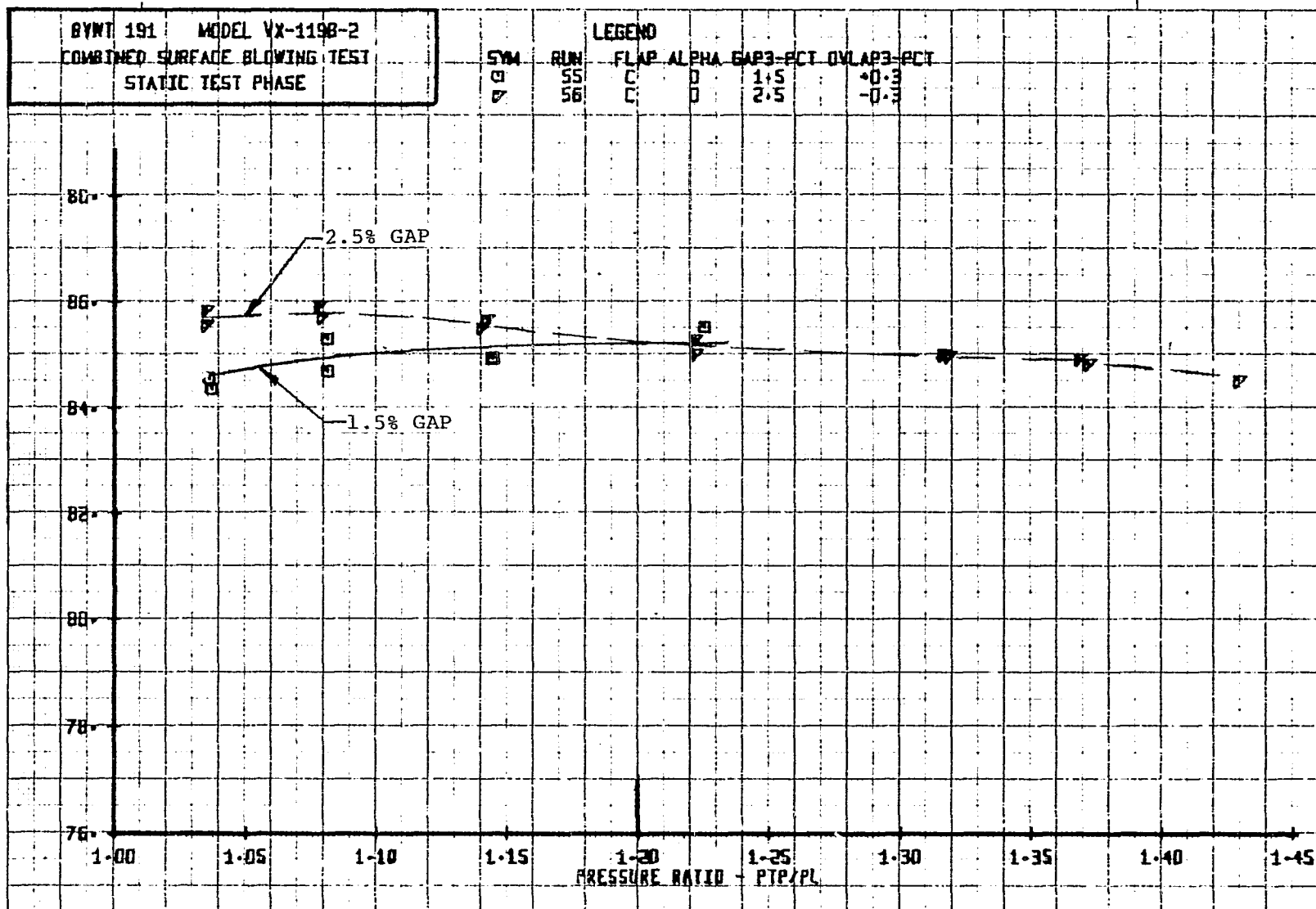


Figure 7.1-38. Flap C, Third Slot Variation
b. Thrust-Deflection Angle

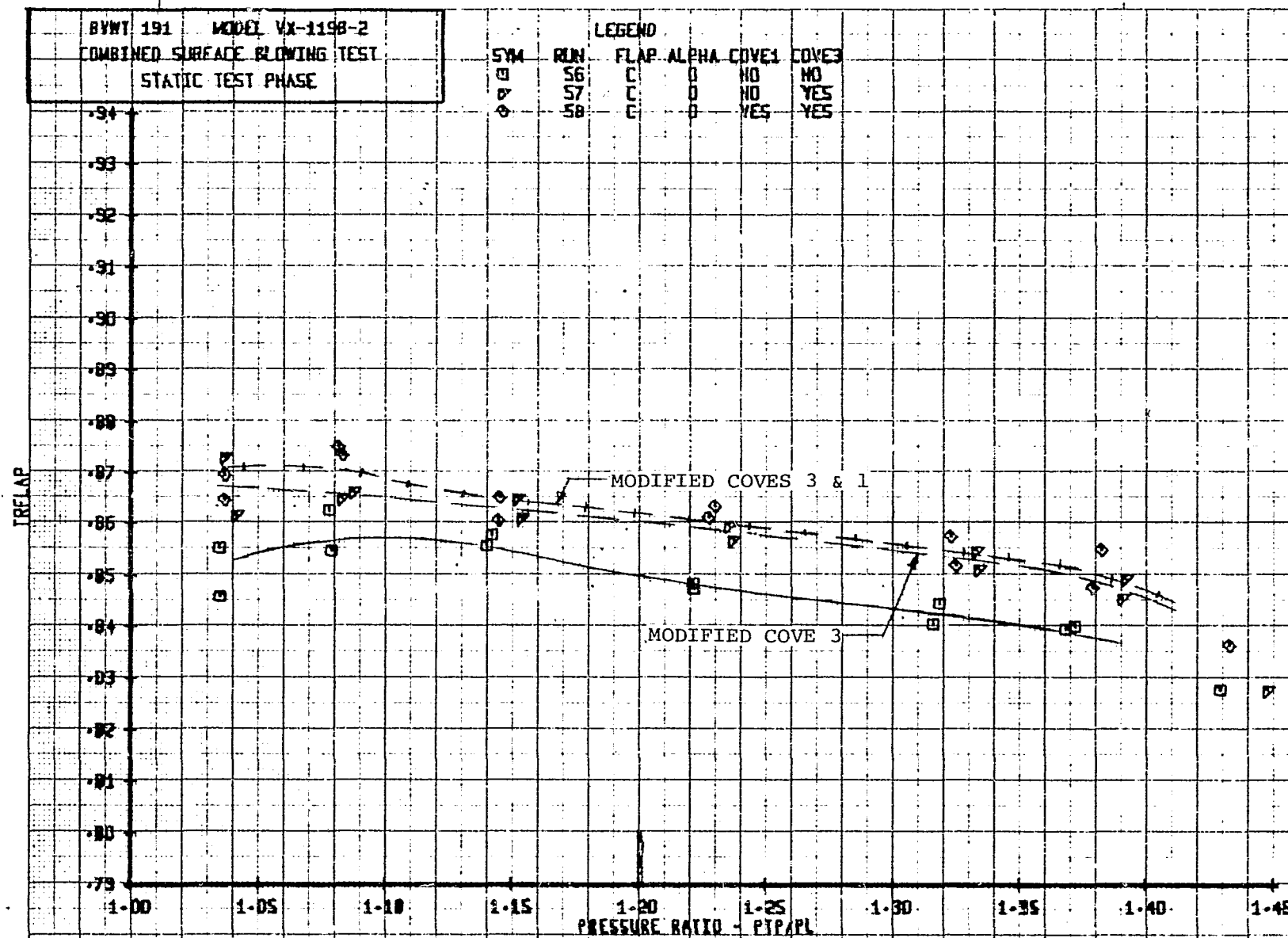


Figure 7.1-39. Flap C, First and Third Slot Cove Modification
a. Thrust Recovery

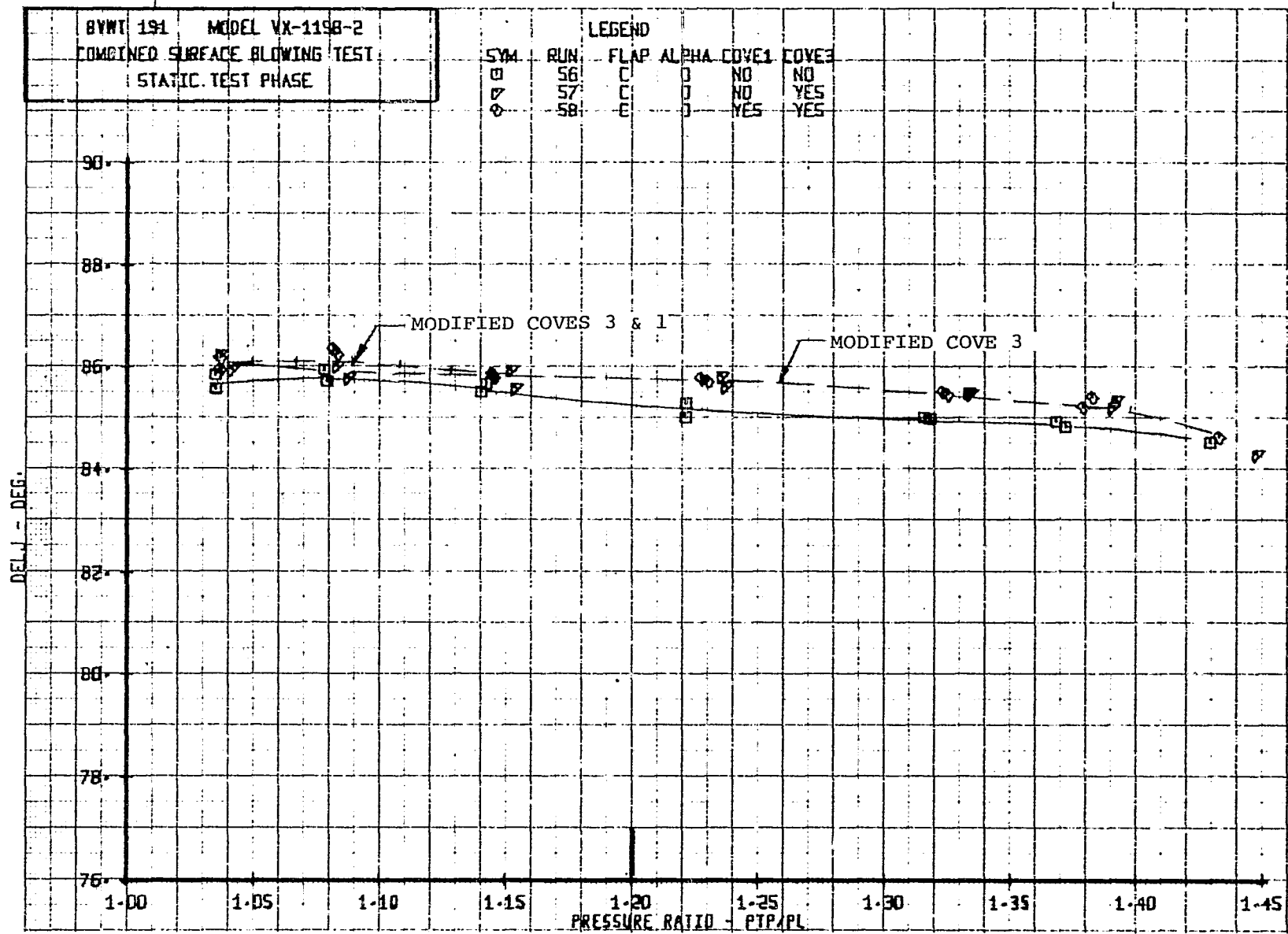


Figure 7.1-39. Flap C, First and Third Slot Cove Modification
 b. Thrust-Deflection Angle

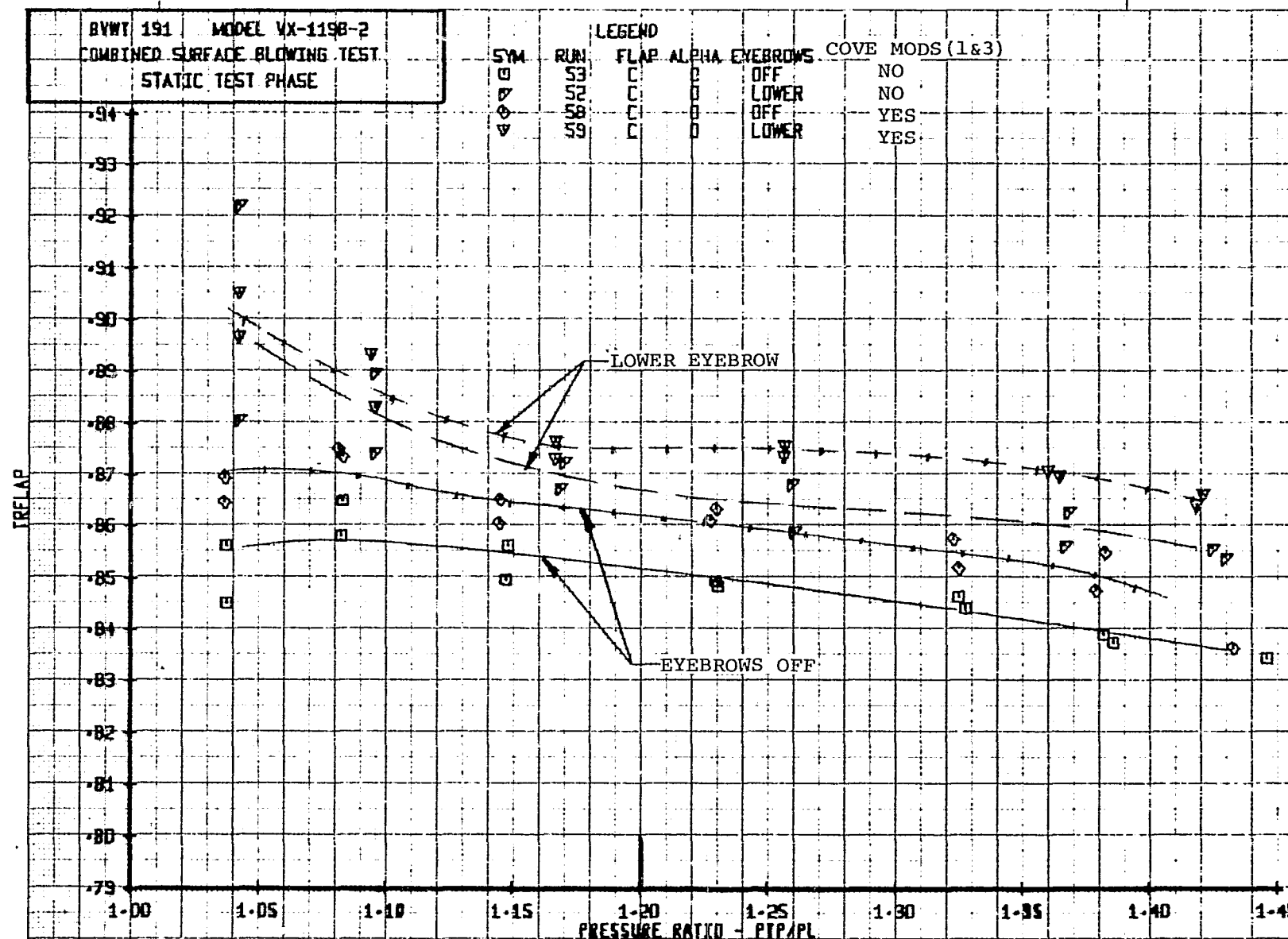
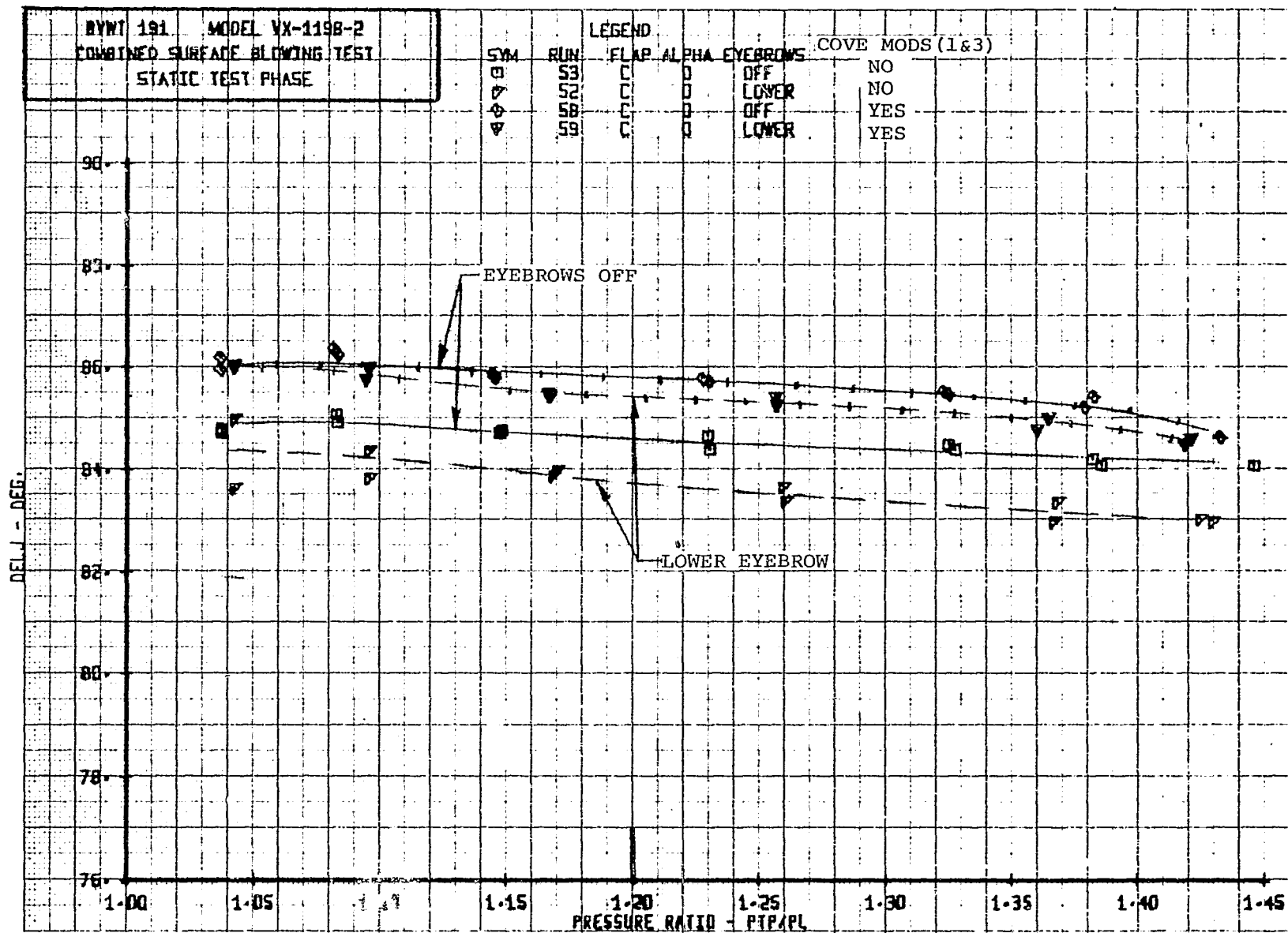


Figure 7.1-40. Flap C, Effect of Lower Eyebrows
a. Thrust Recovery



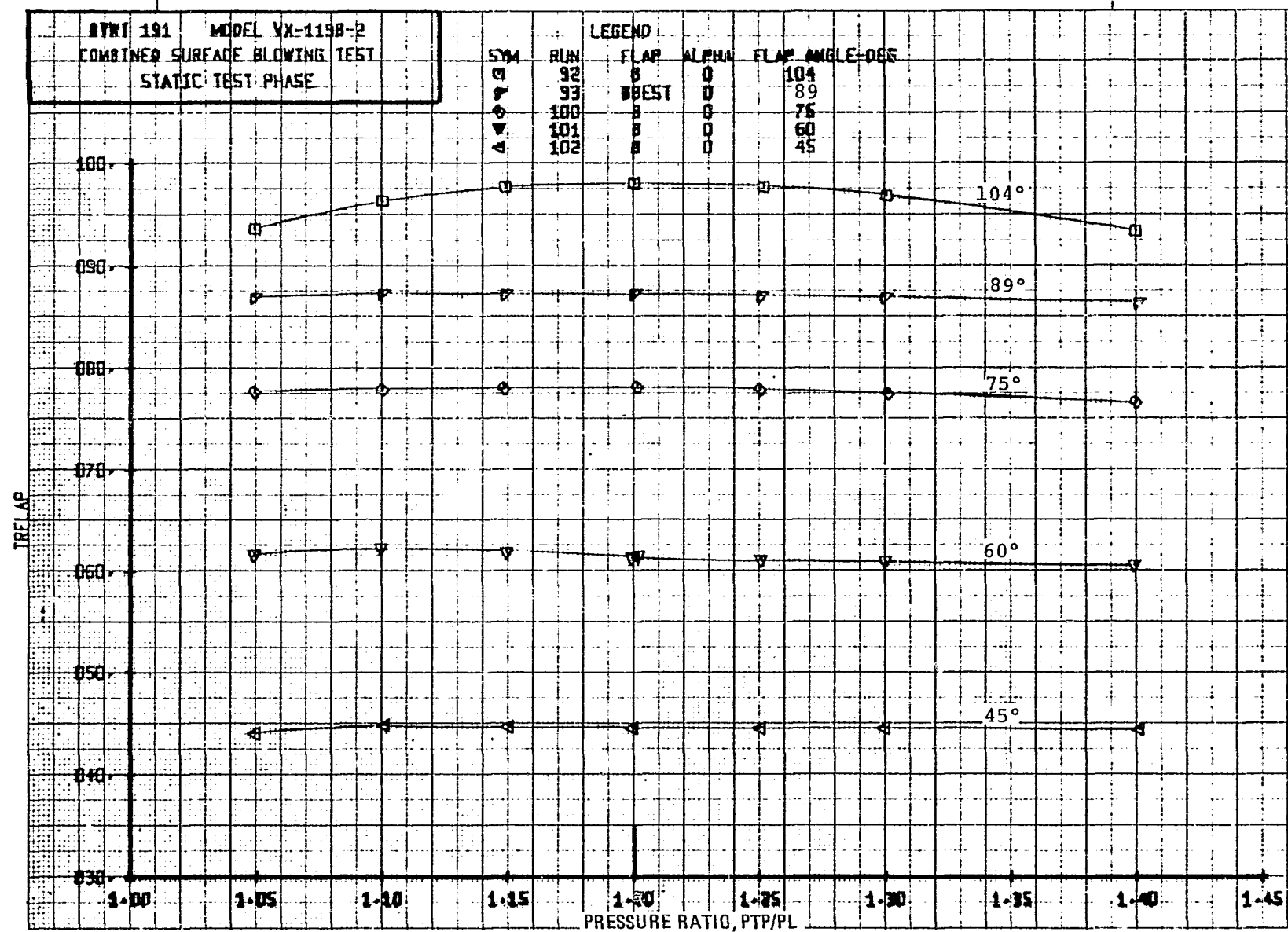


Figure 7.1-41. Effect of Flap Angle
a. Thrust Recovery

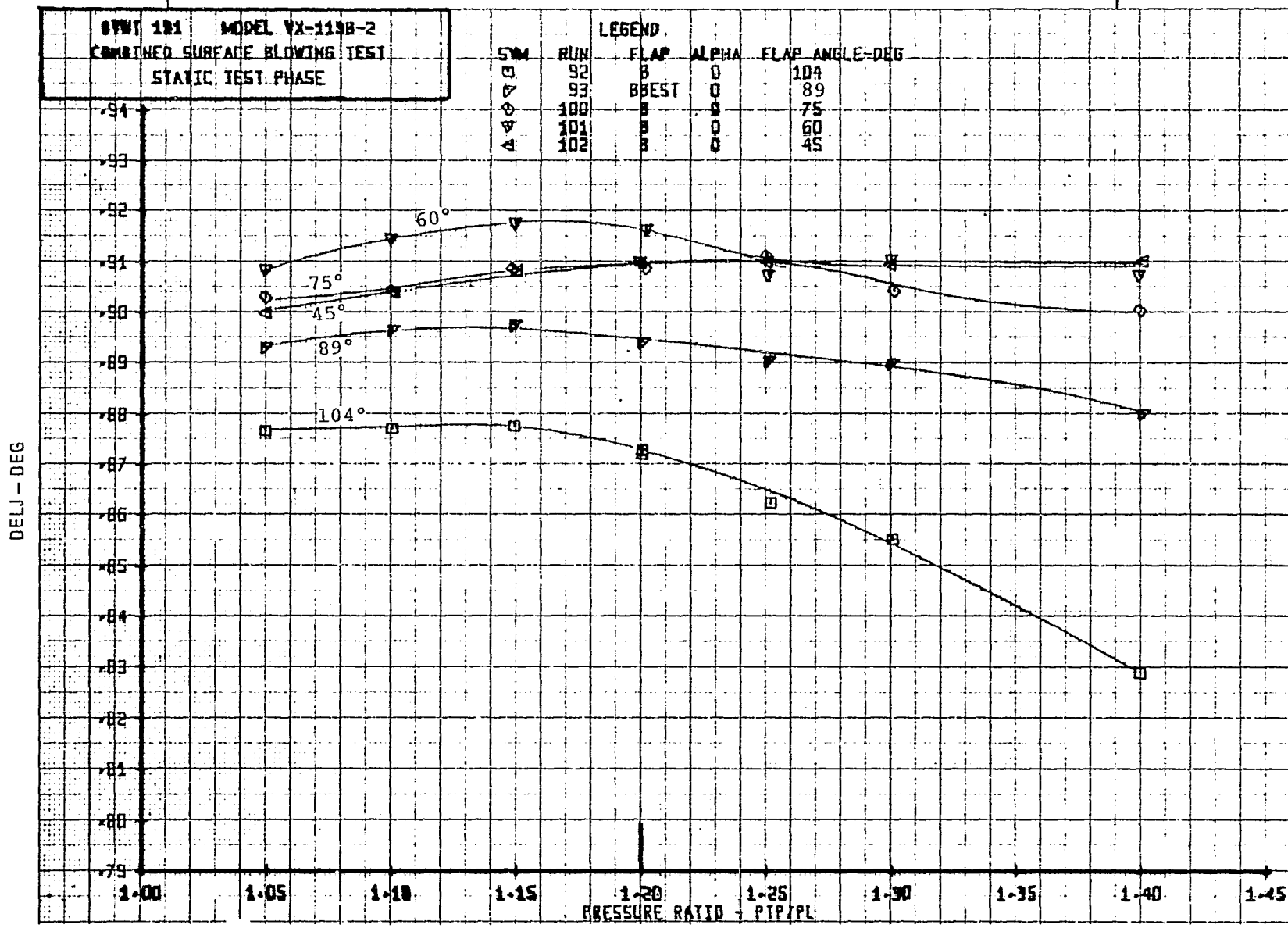


Figure 7.1-41. Effect of Flap Angle
 b. Thrust-Deflection Angle

SYM	RUN	δf
○	102	45°
□	101	60°
△	100	75°
◇	93	89°
▴	92	104°
⬡	37	0°

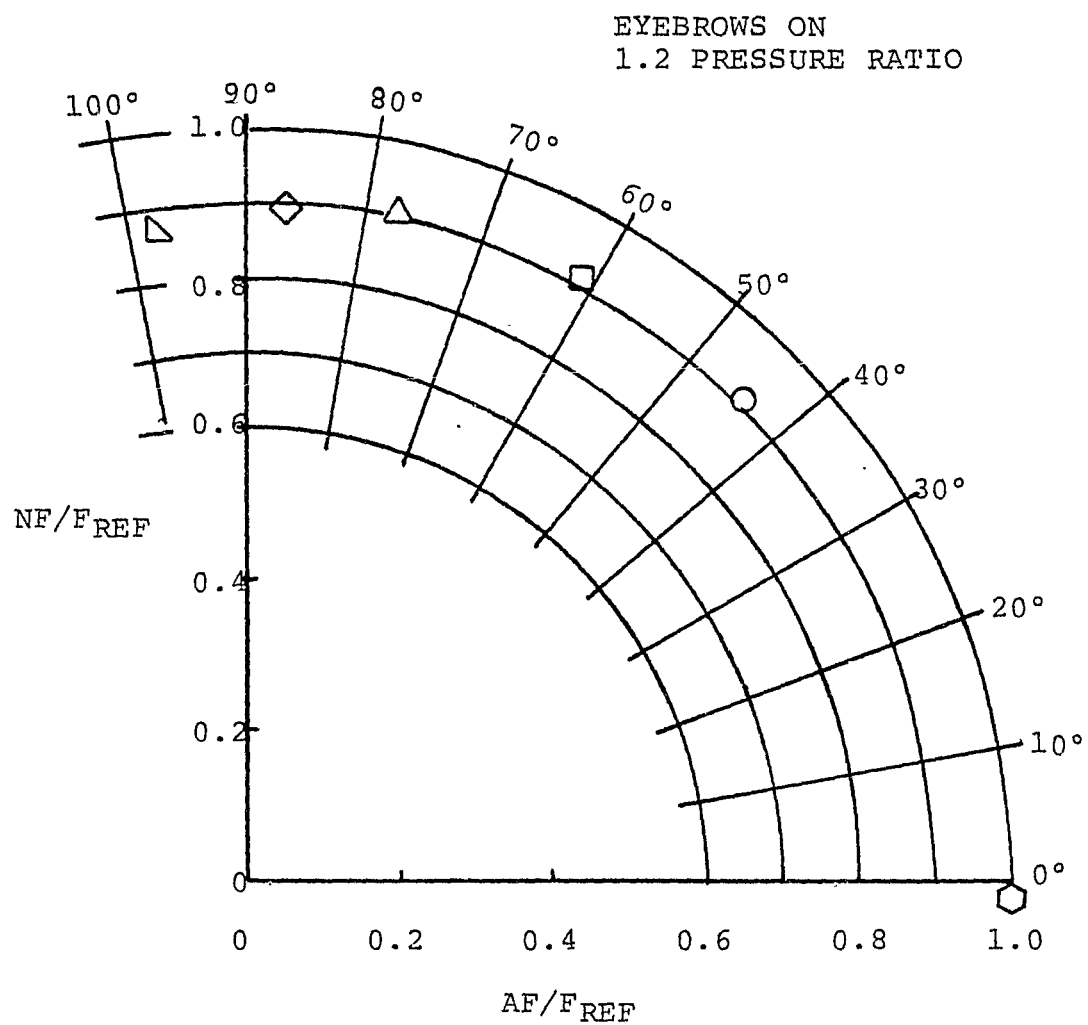


Figure 7.1-42. Flap B Static-Performance Summary Polar

7.2 Static Noise Measurements

Acoustical data was recorded during selected test runs of the model to (1) provide a data base for comparing the acoustical characteristics of the CSB with other types of V/STOL systems, and (2) to determine whether acoustical differences exist when the jet is blown over only the top or bottom of the wing as compared to the design condition of the CSB (blowing over both surfaces).

Noise measurements were obtained during the static performance testing of the model with the selected flap system for the following 12 test conditions:

<u>Test Condition</u>	<u>Flap Setting (deg)</u>	<u>Surface Blowing</u>	<u>Pressure Ratio</u>
1-3	0	Combined	1.05,1.1,1.15,1.2, 1.25,1.3,1.4
		Lower only	Same
		Upper only	Same
4-6	45	Same	Same
7-9	90	Same	Same
10	60	Combined	Same
11	75	Same	Same
12	105	Same	Same

All recorded data (approximately 1,000 points) was reduced to General Radio 1523 graphic-level 1/3-octave-band spectra charts of the type illustrated in Figure 7.2-1.

The effect of flap deflection on the noise-frequency spectra for combined-surface blowing is shown in Figures 7.2-2 through 7.2-5.

Generally, all data displays the same spectral content, which is dominated by high-frequency noise as shown in Figures 7.2-2 and 7.2-3. Exceptions to this occur when the microphones are subjected to excessive test velocities caused by the deflection of the jetstream with various flap settings. When this occurs, as shown in Figure 7.2-4 for 90-degree flaps and Figure 7.2-5 for 0- and 45-degree flaps, the low-frequency noise increases substantially.

In addition, pure tones of noise were found to exist in the 1,000-Hz, 1/3-octave band during all test conditions and occasionally in the 1,250-Hz band at the 1.4 pressure-ratio condition. These tones are shown in the narrow-frequency-band oscilloscope pictures of Figure 7.2-6. The origin of these tones, whether from the air-supply system or due to airflow over the model, has not been clearly determined.

However, in examining the data in 1/3-octave spectra to a frequency of 20 kHz (Figures 7.2-7 and 7.2-8), the two sound-pressure-level peaks that consistently dominate the data are the lower peak (L) centered at approximately 1,000 Hz and the upper peak (H) centered at approximately 5,000–10,000 Hz. The lower-frequency peak (L) appears rather invariant at its value around 1,000 Hz, while the frequency of the upper peak (H) sensed by the downstream microphone is approximately twice that of the upstream microphone.

The amplitude of L is from 5 to 10 db higher at the 90-degree flap setting than it is at the 0 flap setting. The level of H is approximately the same at both flap settings when measured at an azimuth (ψ) of 0, 160, and 270 degrees; and is higher with a flap setting at 90 degrees only below the wing.

Figure 7.2-9 shows comparable data for upper-surface and lower-surface blowing measured below the wing.

The definite variation in the frequency of the upper peak (H) with microphone position is believed to be due to wind aerodynamic noise and not the air pod, while the variation in level of the lower peak (L) is probably due to flap noise. Both frequency ranges require further investigation, with the possibility that sound-power spectral-density analyses of each microphone (and cross-PSD between microphones) might be more enlightening with regard to understanding broadband noise generation than the 1/3-octave analysis.

7.3 Transition-Performance Test Results

7.3.1 Aerodynamics with extended wing. — Following completion of acoustic testing, the wind tunnel was reconfigured for transition tests. The wind-tunnel walls and ceiling were reinstalled in the slotted configuration. In addition, a sheetmetal fairing was placed around the balance and pedestal below the fixed ground plane in order to eliminate airloads on the balance. A repeat static run was made with the walls installed to check on possible wall interference during subsequent runs at high thrust coefficients. Figures 7.3-1a and 7.3-1b compare data for thrust recovery and thrust-deflection angle, respectively, from runs 83 and 91 (walls removed) with data from runs 107 and 108 (slotted walls installed). The data scatter on thrust recovery increases substantially with the walls installed — an indication that scatter during the static-performance phase may have been due to flow recirculation. However, the overall scatter and the repeatability with the previously obtained open-throat data are quite good when measured in terms of possible wall-interference effects during wind-on testing.

7.3.1.1 Effect of air pod: The effect of the air pod and nozzle on the clean-wing aerodynamics (flaps and slats retracted) were determined in runs 111 through 113. These effects are shown in Figure 7.3-2. Three different conditions were tested:

- Air pod and nozzle on with no blowing (zero gross thrust). This created a base region behind the nozzle of turbulent separated flow, with an accompanying reduction in lift and increase in drag.
- Air pod and nozzle on with the blowing controlled so that the exit-jet Mach number was equal to the freestream Mach number. This filled in the region of separated wake and corresponds to a condition of zero net thrust.
- Air pod and nozzle removed. This reduced the drag to the lowest level of the three conditions tested since the skin friction of the nozzle and air pod was eliminated. It also provided a lift curve nearly identical to the zero-net-thrust condition except for the region near stall where the uneven leading edge of the wing with the air pod removed (the filleted juncture where the air-pod feed line enters the wing) caused premature separation.

During subsequent runs in the transition-phase testing, the power-off condition was represented by running the model at zero net thrust.

7.3.1.2 Slat effectiveness: Figure 7.3-3 shows the effect of leading-edge slat position on the power-off aerodynamics with the trailing-edge flap retracted. Stall angle of attack varies from 30 degrees to over 35 degrees. As expected, the steepest slat setting provides the highest wing stall angle, although $C_{L_{max}}$ is approximately the same for the three settings tested.

Slat-effectiveness studies were repeated with power on and with the trailing-edge flap set to 45-degree deflection. Figure 7.3-4 shows the results of this study at thrust coefficient $C_j = 2$, and Figure 7.3-5 shows the corresponding results when $C_j = 4$. Four different slat settings were investigated: two in which the settings inboard and outboard of the blown air pod were equal (45 degrees in one case, 51 degrees in the other) and two in which the inboard slat was set at a steeper angle than for the outboard slat. The steepest inboard-slat setting (56 degrees) for run 130 in Figure 7.3-4 used a refaired contour to increase the overall radius of surface curvature. From these runs, the slat was set at 51 degrees inboard and 45 degrees outboard for the remainder of the power-on testing. This was based on achieving high $C_{L_{max}}$ in combination with high negative C_x at $C_{L_{max}}$, in order to achieve steep descent capability.

7.3.1.3 Flow visualization with extended wing: Figure 7.3-6 shows the flow pattern on the wing upper surface as determined from tuft studies at $C_j = 2$ (run 137). Trailing-edge flaps were deflected 45 degrees. A limited region of separation is seen on the upper surface adjacent to the fuselage just forward of the trailing-edge flaps. In the photo sequence, the separation begins at 9 degrees angle of attack and gradually grows in extent until, at $\alpha = 28$ degrees, the majority of the mid-upper surface of the inboard third of the wing is stalled. Note that the outboard third of the wing is unstalled at $\alpha = 28$ degrees.

In order to contain this region of separation, a fence was attached to the wing upper surface, one inch in height, extending from the slat leading edge to the first flap slot. The fence was positioned three inches outboard of the side of the body. A flow study with the

fence installed is shown in Figure 7.3-7. Although the separated region is suppressed at low angle of attack (compare, for example, $\alpha = 12$ degrees from 7.3-6c and 7.3-7e), the fence is unable to contain the separation at the higher angles of attack. Figure 7.3-8 compares the aerodynamic characteristics with the fence on and off.

7.3.1.4 Reduced inboard-flap deflection: Runs were made with the inboard trailing-edge flap set at a lower deflection than either the mid (blown) flap or the outboard flap, in order to reduce the aerodynamic loading and thus suppress the stall on the inboard wing panel. These runs (runs 148–154) used 75 degrees of deflection on the two outer-flap panels and 45 degrees of deflection on the inner flap. In addition to reducing the inboard-flap deflection, a further adjustment was made on the leading edge by replacing the inboard slat (between the nozzle and side of body) with a drooped leading edge. The result of these changes is shown in Figures 7.3-9 for $C_j = 4$ and 7.3-10 for $C_j = 8$. The lift coefficient is reduced at low angle of attack due to the reduced inboard-flap deflection when the leading edge consists of the slat at the 51-degree setting. When the slat was replaced by the droop-nose leading edge, much of the lift loss was eliminated. Overall, the reduced inboard-flap setting did not produce the anticipated improvement in maximum lift coefficient or angle of stall.

7.3.1.5 Extended-wing performance, flap deflection = 45 degrees: Figure 7.3-11 shows the aerodynamic performance of the extended wing with the 45-degree flap deflection from runs 133 through 136. Leading-edge slat configuration is $S_1 S_3$ (51 degrees inboard, 45 degrees outboard). For comparison, the aerodynamics with the slat set uniformly at 51 degrees (S_1 setting) is shown in Figure 7.3-12 from runs 123, 125, and 131. Part d of each of these figures shows the circulatory component of the lift coefficient ($C_L - C_j \sin(\alpha + \delta_f)$). The increment between the power-off and the power-on data represents the jet-induced lift (or supercirculation effect). The induced lift is analyzed in Section 7.3.3.

7.3.1.6 Extended-wing performance, flap deflection = 75 degrees: The aerodynamic characteristics of the extended-wing configuration with flap deflection of 75 degrees are shown in Figure 7.3-13. The slat is configured in the $S_1 S_3$ setting.

7.3.2 Aerodynamics with retracted wing. —

7.3.2.1 Retracted-wing performance: Figures 7.3-14 through 7.3-18 show the aerodynamic characteristics of the retracted wing for flap deflections between 45 and 100 degrees. For the 90-degree flap deflection, the outboard (unblown) flap was set to 75 degrees and for the 100-degree deflection the outboard flap was reduced to 45 degrees. Part e of each figure presents an analysis of induced drag. Jet-flap theory (see, for example, ref. 2) predicts that the induced drag of the jet flap can be written as:

$$-C_x = \underbrace{\frac{C_L^2}{\pi AR + 2 C_j}}_{-C_j} \quad \text{This term is labeled Ind Drag on part e of Figures 7.3-14 through 7.3-18.}$$

This relationship assumes elliptical distributions of circulation and thrust coefficient along the wingspan. Assuming nonelliptical distributions for a real wing, it would appear reasonable to write:

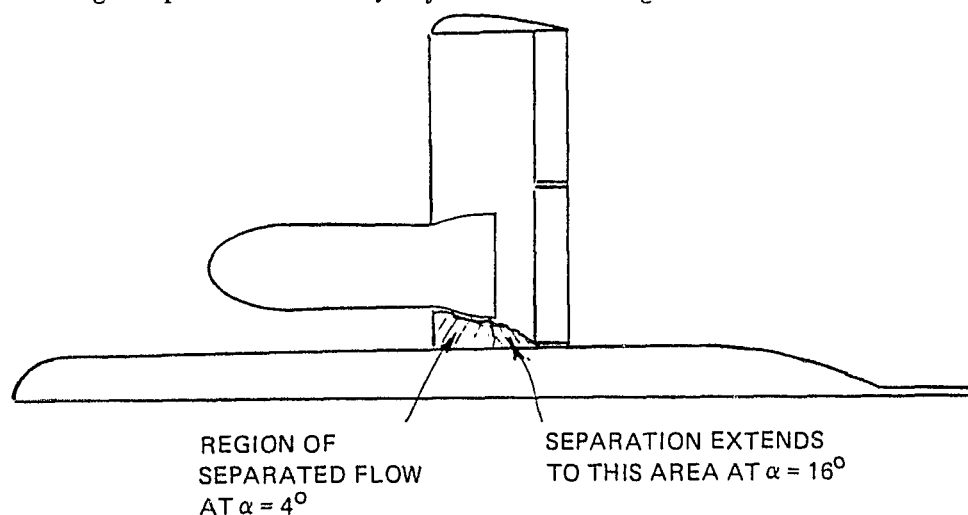
$$C_j - C_x = \frac{1}{e} \frac{C_L^2}{\pi AR + 2 C_j} = \frac{1}{e} (\text{Ind Drag})$$

where e is a span-loading efficiency similar to the Oswald's efficiency factor used for conventional airplane configurations. Examination of the data of Figures 7.3-14 through 7.3-18 shows that e varies in the following manner as a function of flap deflection:

Flap Deflection (deg)	e
45	0.588
60	0.595
75	0.541
90/75	0.500
100/45	0.380

For the retracted-wing testing, the slot gaps and overlaps on the outboard unblown-flap segment were reduced to levels consistent with unpowered high-lift system design, while the blown flap had larger slot gaps determined from the static-phase test. The leading-edge slat was set in the S_3 configuration (45-degree deflection) in the region outboard of the nacelle. Between the body and the nacelle, the leading edge was fitted with a droop nose.

7.3.2.2 Flow visualization with the retracted wing: Tuft studies were made with the retracted-wing configuration. These showed that a small region of separation developed at approximately a 4-degree angle of attack in the area between the body and the side of the nozzle, extending from the wing leading edge to the nozzle exit. At $\alpha = 16$ degrees, the region extended chordwise into a wedge-shaped area from the side of the nacelle to the side of the body at the leading edge of the first flap element. This is shown in the following sketch. At $\alpha = 18$ degrees, the separated region spread to the body adjacent to the wing.



The blown portion of the wing and the outboard unblown panel had fully attached flow to angles of attack generally in excess of 25 degrees.

7.3.3 Induced lift. — The aerodynamic performance data from the retracted-wing runs was analyzed to determine the level of incremental circulatory lift induced on the wing by the jet. The jet-induced lift coefficient was defined as:

$$\Delta C_L \equiv \underset{\substack{\uparrow \\ \text{power-on}}}{C_L} - \underset{\substack{\uparrow \\ \text{power-off} \\ \text{at } F_{\text{net}} = 0}}{C_{L,0}} - \underbrace{C_j \sin(\alpha + \delta_f)}_{\substack{\uparrow \text{deflected-thrust} \\ \text{contribution}}}$$

Figures 7.3-19 through 7.3-21 show the jet-induced lift at zero angle of attack for flap deflections of 45, 60, and 75 degrees. This data was obtained from q variation runs at constant $\alpha = 0$. The results clearly indicate a dependence of ΔC_L on the jet Mach number, as well as on the thrust coefficient. For values of jet Mach number below a threshold value of 0.4 to 0.5, the induced-lift coefficient curves collapse into a single curve, dependent only upon thrust coefficient.

The induced-lift curves are summarized in Figures 7.3-22 and 7.3-23 in terms of the values achieved at low jet Mach numbers (Figure 7.3-22) and the loss associated with the jet Mach number effect (Figure 7.3-23). Figure 7.3-23 shows that the sensitivity to jet Mach number increases with increasing flap-deflection angle.

Figure 7.3-24 compares the induced-lift levels obtained from the test with theoretical values of ΔC_L for a pure jet-flap wing of the same aspect ratio (theory of reference 3). The induced lift from the test is 55 percent of the theoretical value for the fullspan jet flap, although the nozzle width was only 27.5 percent of the wingspan.

7.3.4 Tail-downwash environment. — A series of runs was made with the retracted-wing configuration to determine the downwash environment at a typical position for a horizontal tail. A downwash rake (shown in Figure 7.3-25) was mounted on the vertical tail at a position 3.85 chord-lengths behind and 1.22 chord-lengths above the wing quarter-chord line. The rake consisted of a rod extending spanwise from the fuselage centerline mounted on a rotary potentiometer. The rod contained four vanes located at 7.0, 11.0, 15.0, and 19.0 inches from the fuselage center (for comparison, the wing-body juncture was 4.75 inches from the center of the fuselage and the center of the air pod was 12.875 inches from the fuselage center). The rod was free to rotate on the rotary potentiometer. Total head probes were located at spanwise positions of 9.0, 13.0, and 17.0 inches from the center of the body and a single static orifice was at a spanwise position of 5.5 inches from the body center. Thus the rake provided an average direction and magnitude of local air velocity in the region behind the inner (blown) flap segment. Figures 7.3-26 through 7.3-31 show the downwash angle and local dynamic pressure in this region. The curves cover flap deflections of 45 through 100 degrees in the following order:

Flap Deflection (deg)	Figure No.
45	7.3-26
60	7.3-27
75	7.3-28
90/45	7.3-29
90/75	7.3-30
100/45	7.3-31

Inboard wing stall is evident in the dynamic-pressure ratio curves by the abrupt decrease in pressure as measured by the rake. A summary of this data at $\alpha = 0$ is shown in Figure 7.3-32 as a function of thrust coefficient and flap deflection. The data is consistent with other jet-flap downwash characteristics reported in the literature.

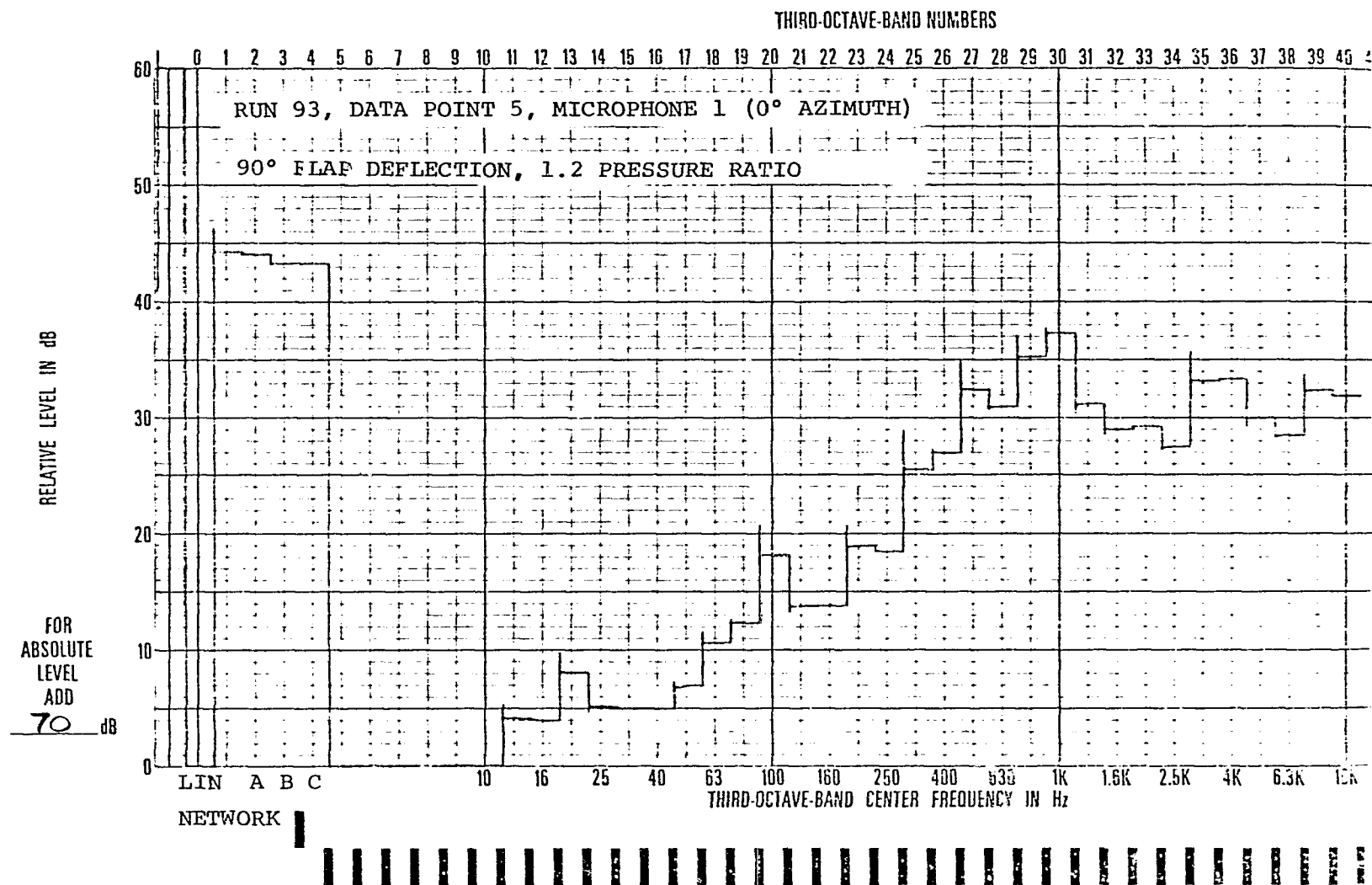


Figure 7.2-1. Example of General Radio 1/3-Octave-Band Spectra Chart

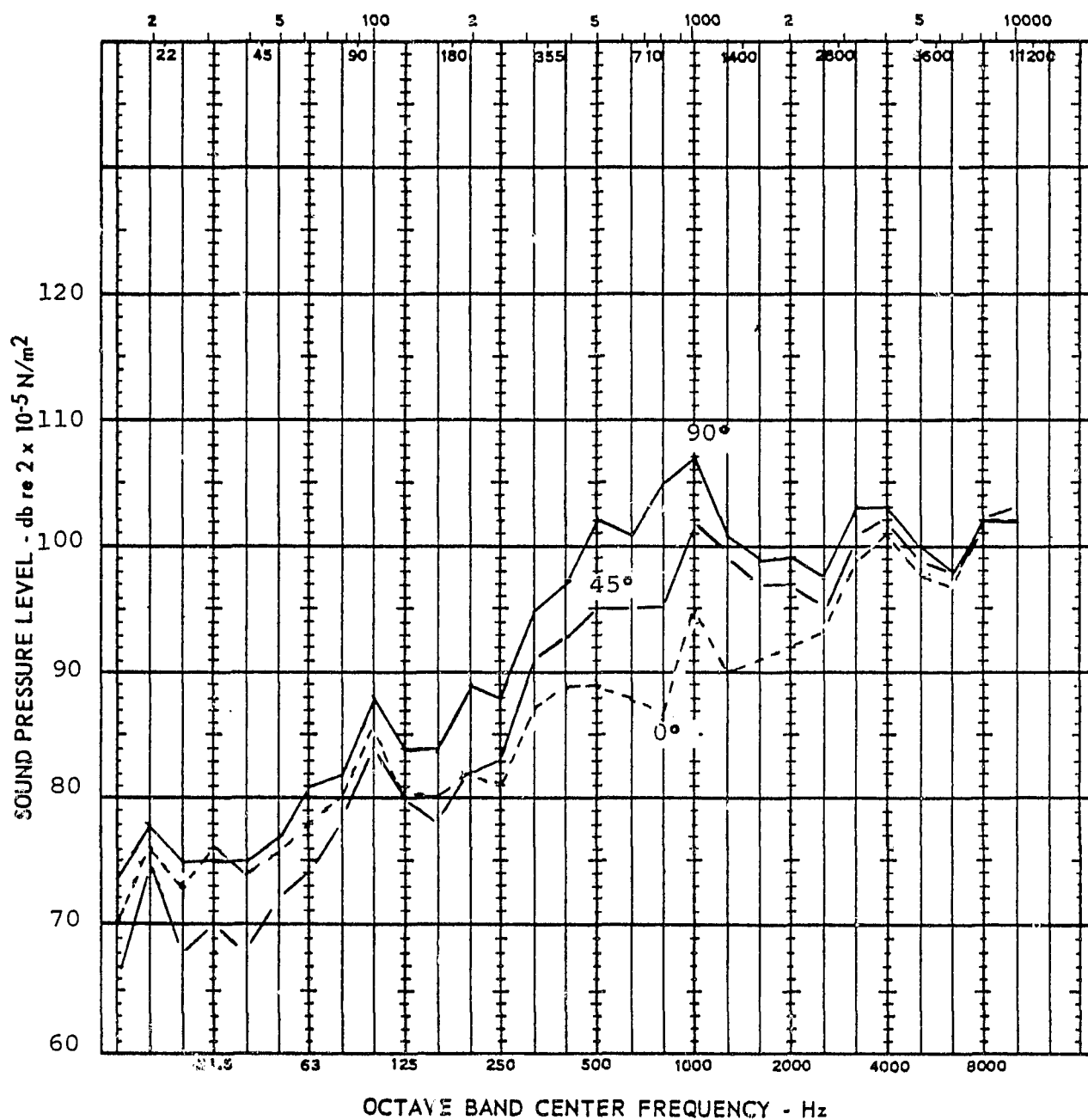


Figure 7.2-2. Comparison of Noise-Frequency Spectra for 0°, 45°, 90° Flap Deflections Measured at 0° Azimuth

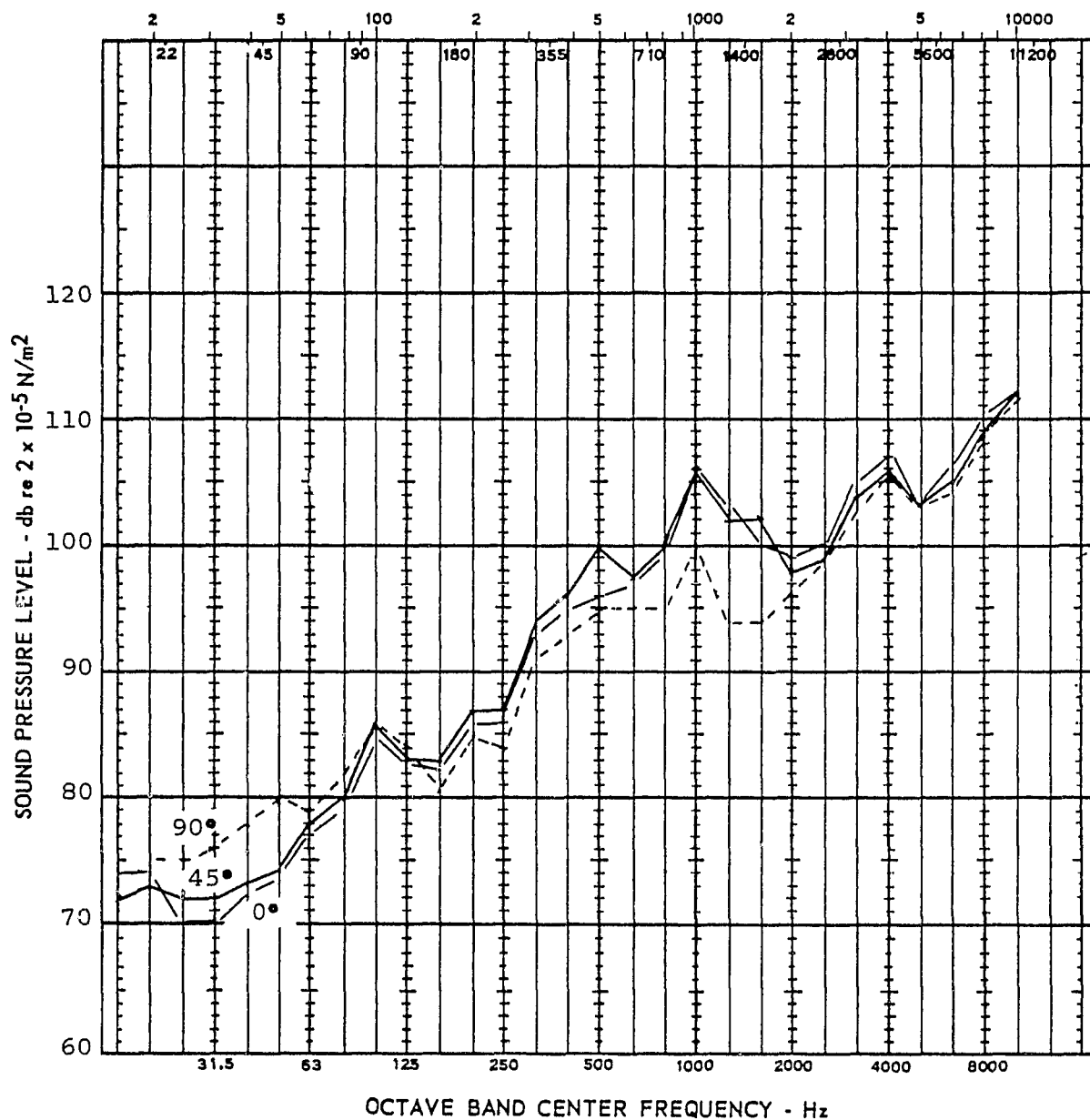


Figure 7.2-3. Comparison of Noise-Frequency Spectra for 0°, 45°, 90° Flap Deflections Measured at 270° Azimuth

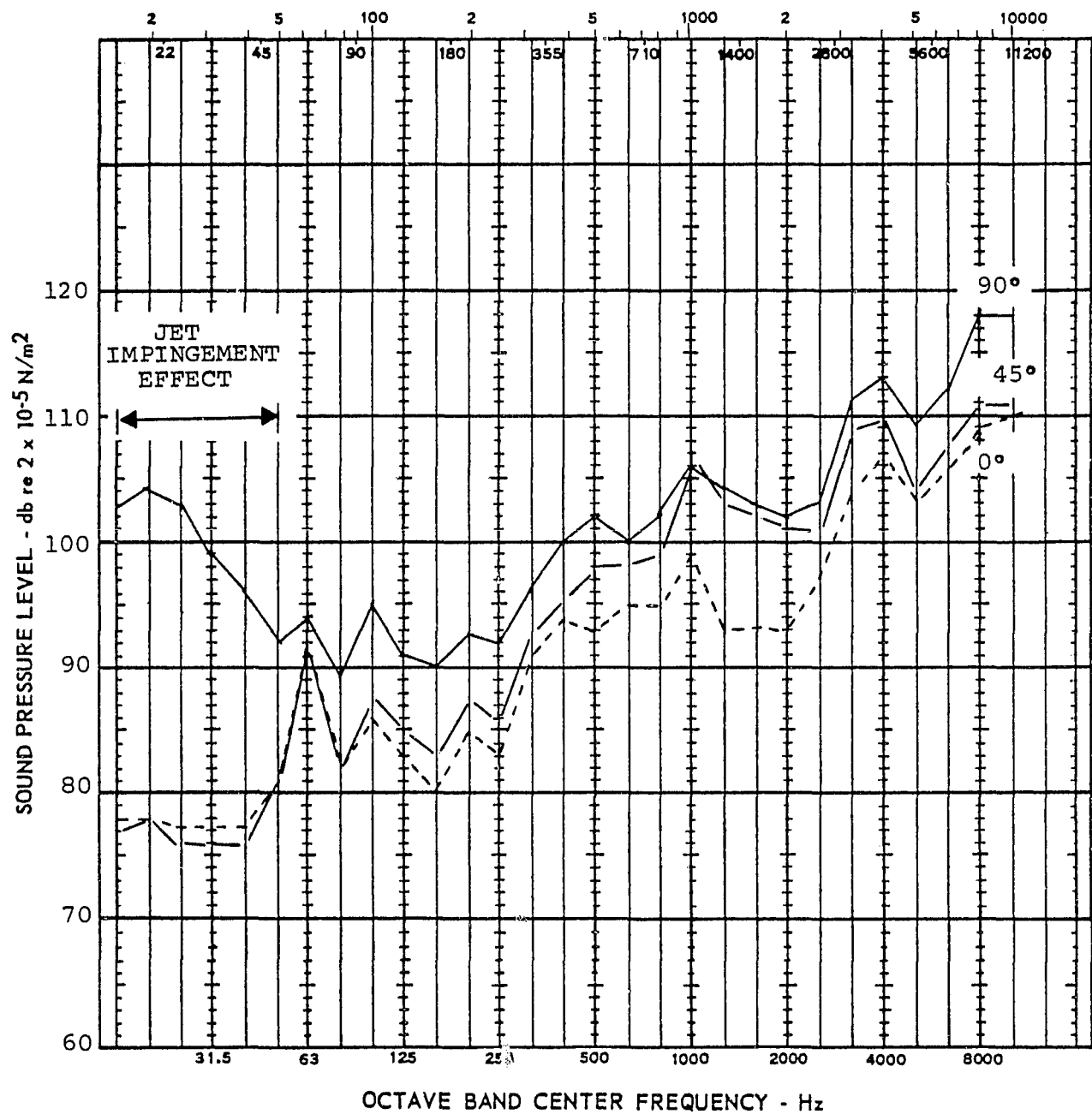


Figure 7.2-4. Comparison of Noise-Frequency Spectra for 0°, 45°, 90° Flap Deflections Measured at 80° Azimuth

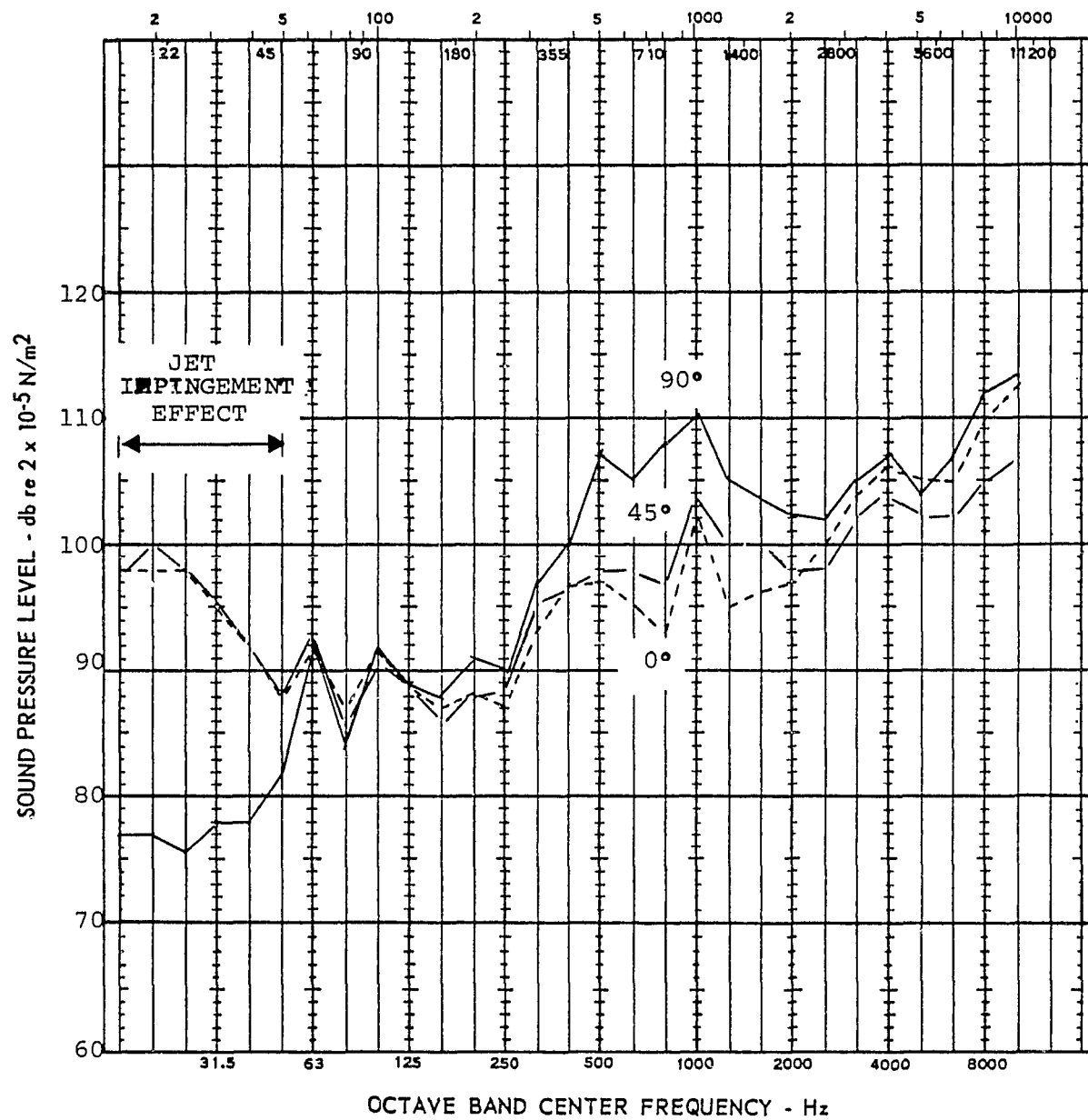
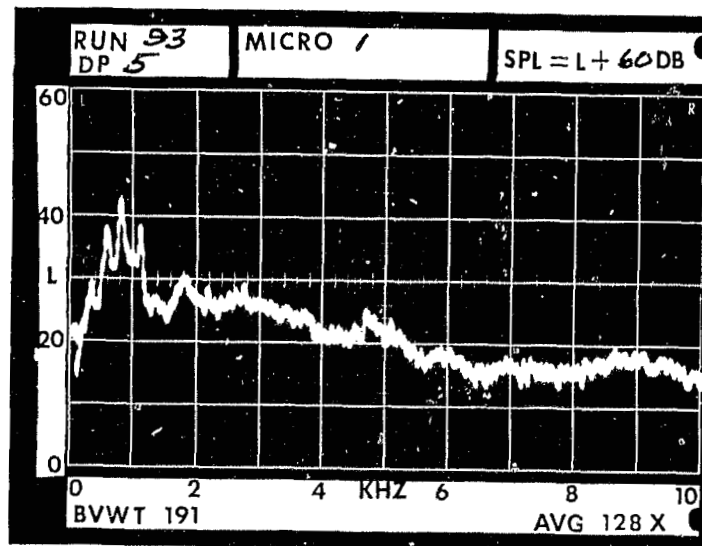
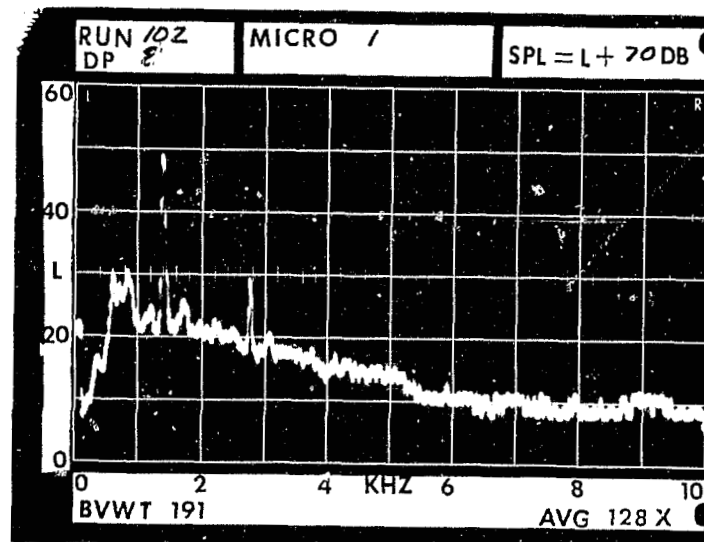


Figure 7.2-5. Comparison of Noise-Frequency Spectra for 0°, 45°, 90° Flap Deflections Measured at 160° Azimuth



0° AZIMUTH
90° FLAP
DEFLECTION
1.2 PRESSURE
RATIO



0° AZIMUTH
45° FLAP
DEFLECTION
1.4 PRESSURE
RATIO

Figure 7.2-6. Narrow-Frequency-Band Analysis of CSB Model Noise

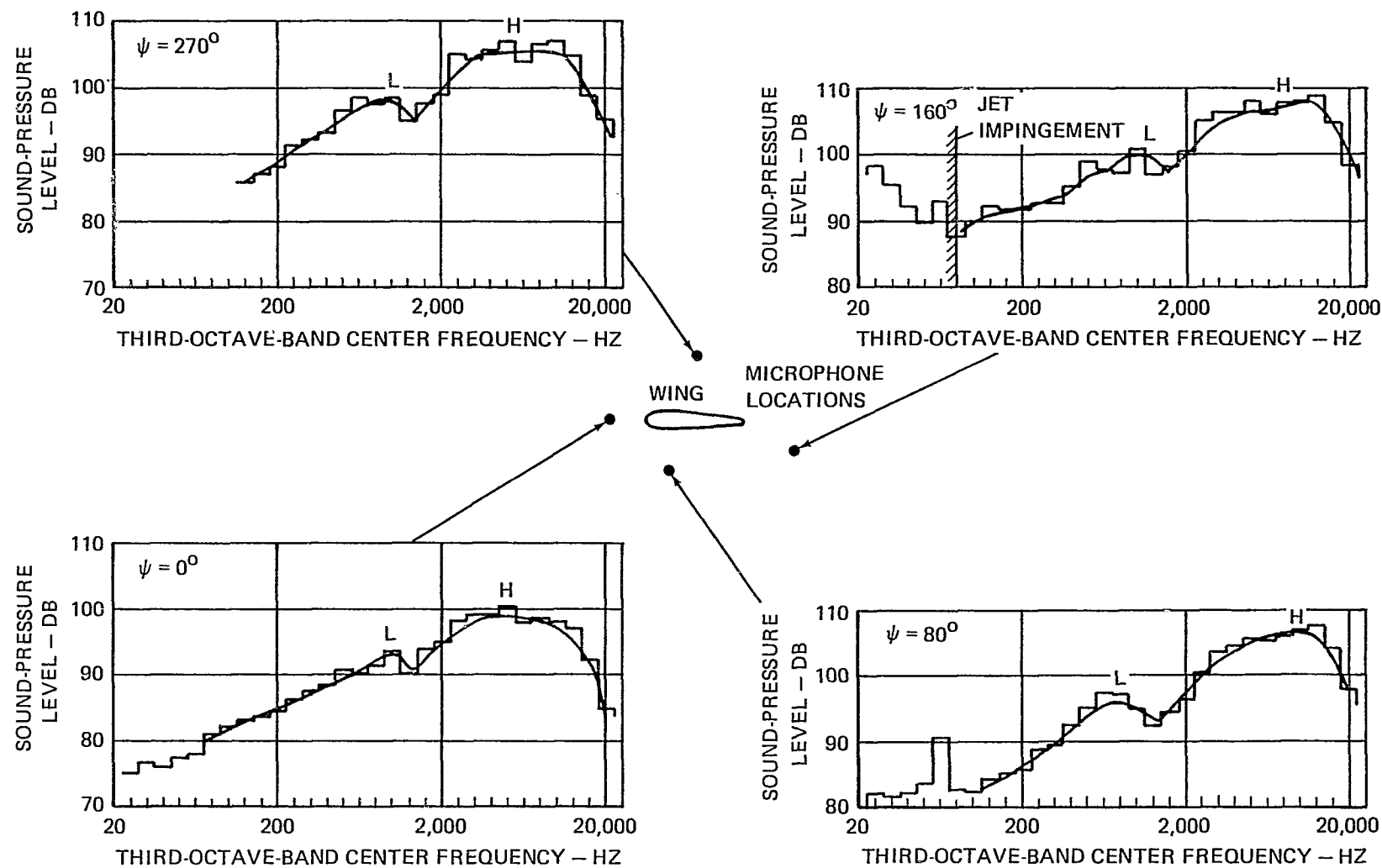


Figure 7.2-7. Comparison of Noise-Frequency Spectra for Combined-Surface Blowing With 0° Flap Deflection at $0, 80, 160$, and 270° Azimuth Locations

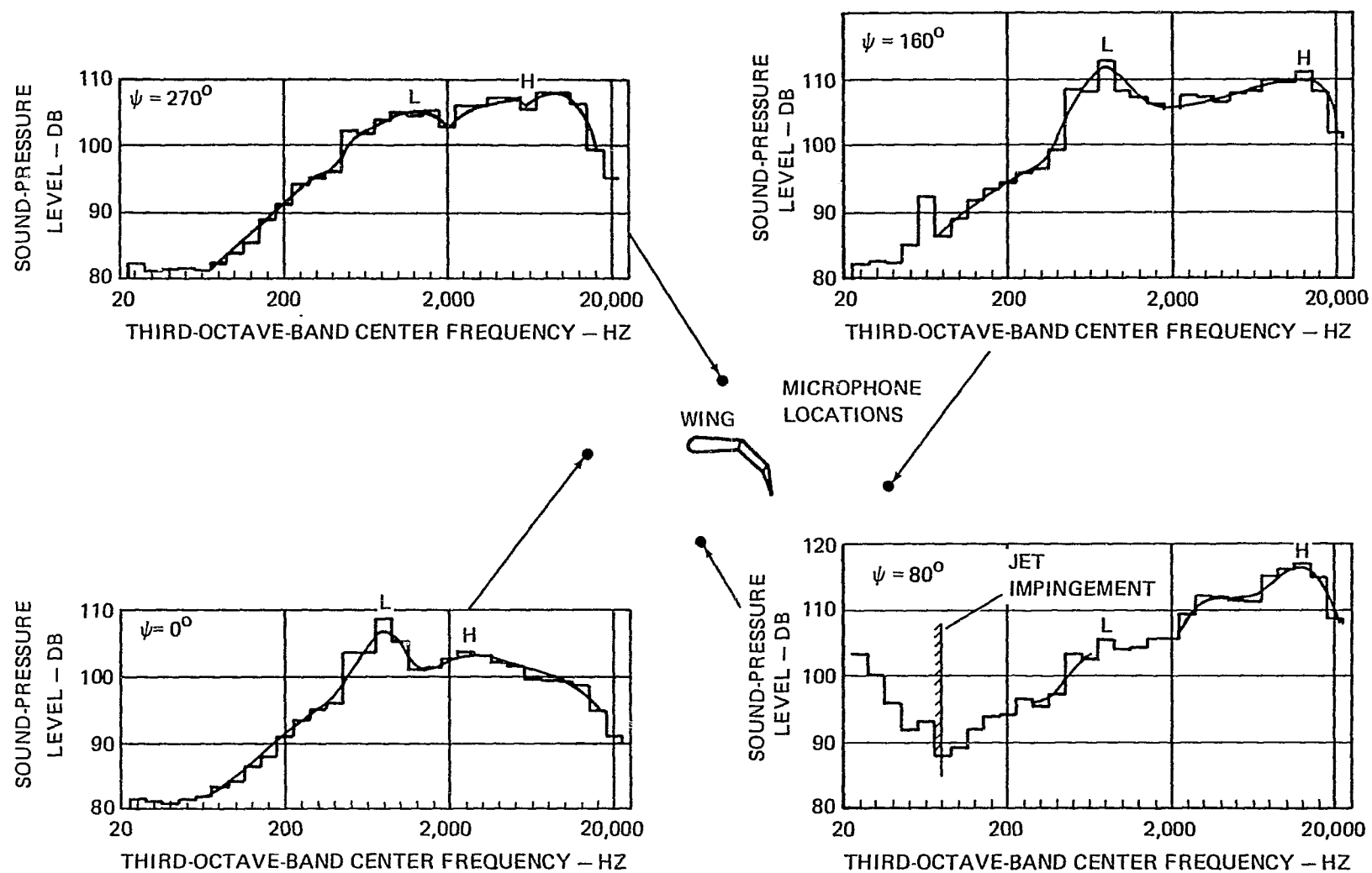


Figure 7.2-8. Comparison of Noise-Frequency Spectra for Combined-Surface Blowing With 90° Flap Deflection at 0, 80, 160, and 270° Azimuth Locations

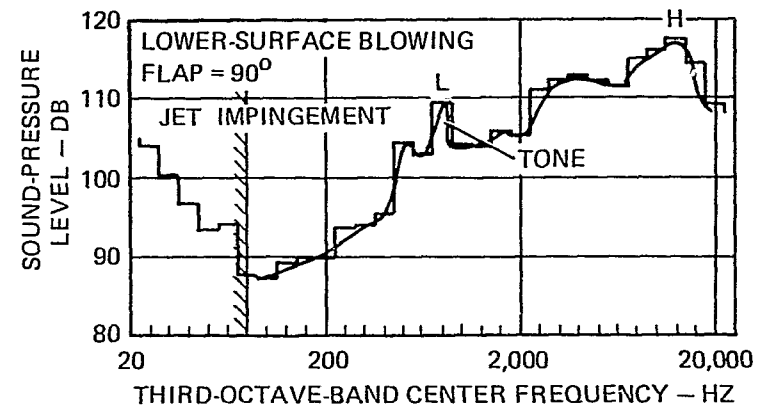
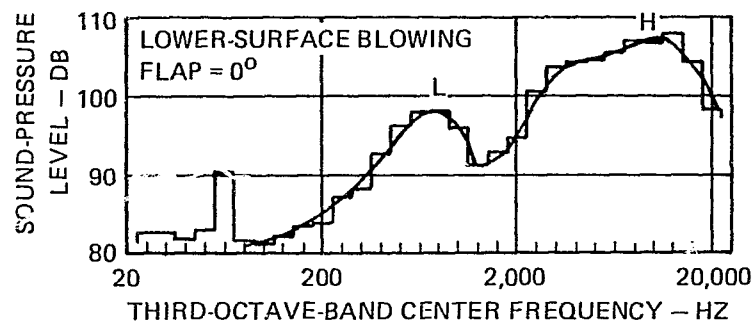
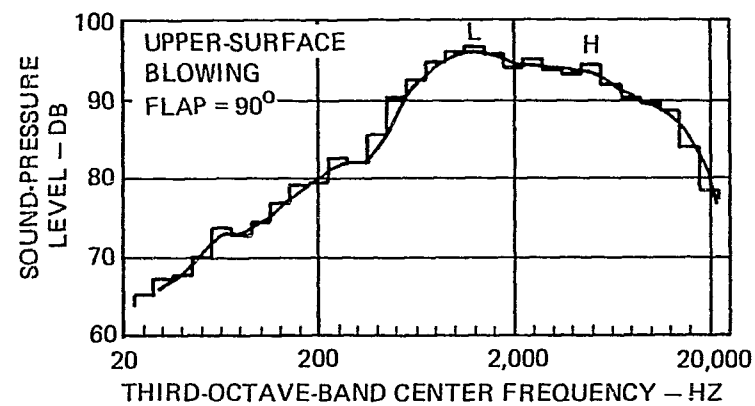
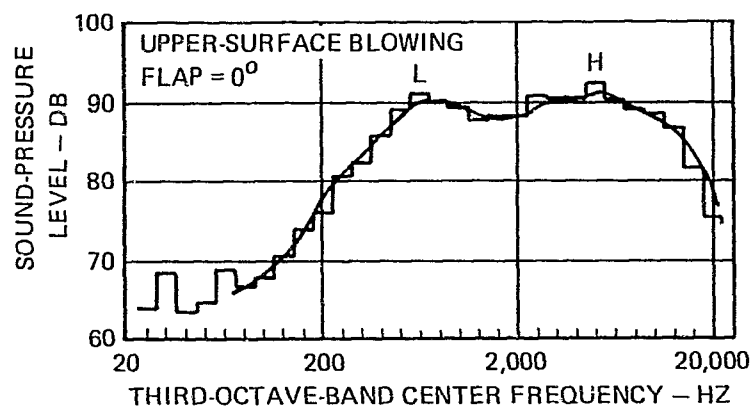


Figure 7.2-9. Comparison of Noise-Frequency Spectra for Upper- and Lower-Surface Blowing With 0 and 90° Flap Deflections at an Azimuth Location of 80°

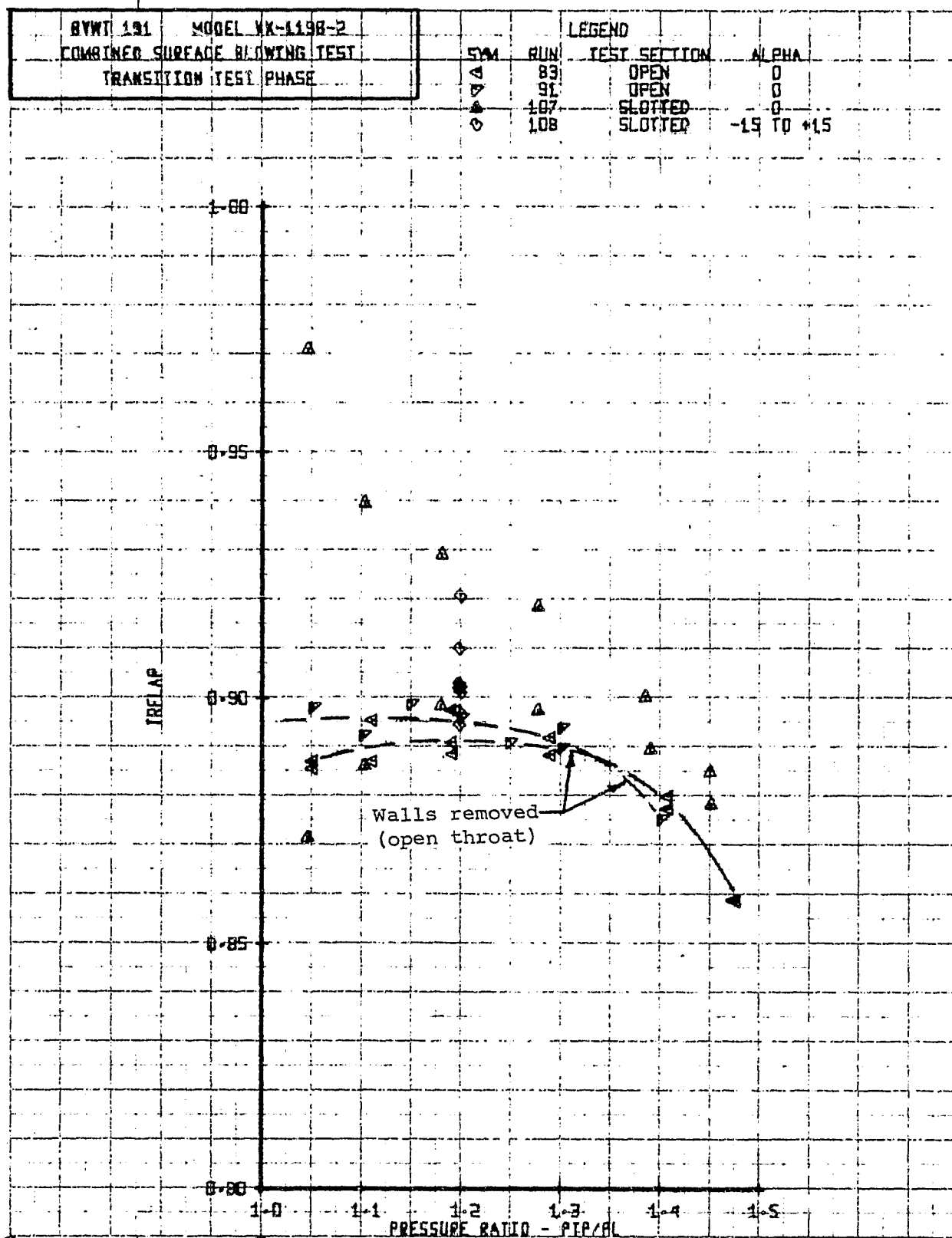


Figure 7.3-1. Wall Effects Under Static-Test Conditions
a. Thrust Recovery

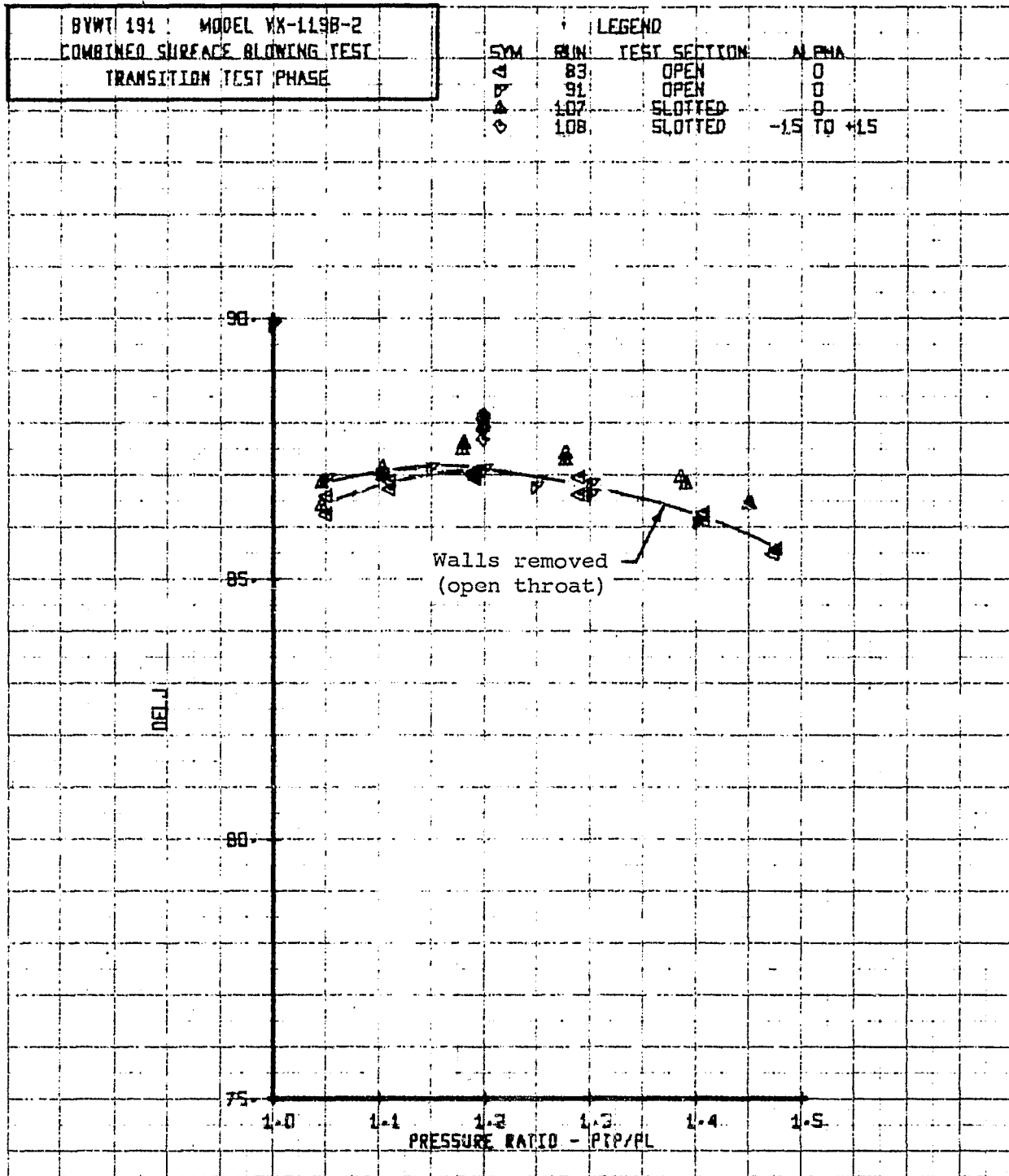


Figure 7.3-1. Wall Effects Under Static-Test Conditions
b. Thrust-Deflection Angle

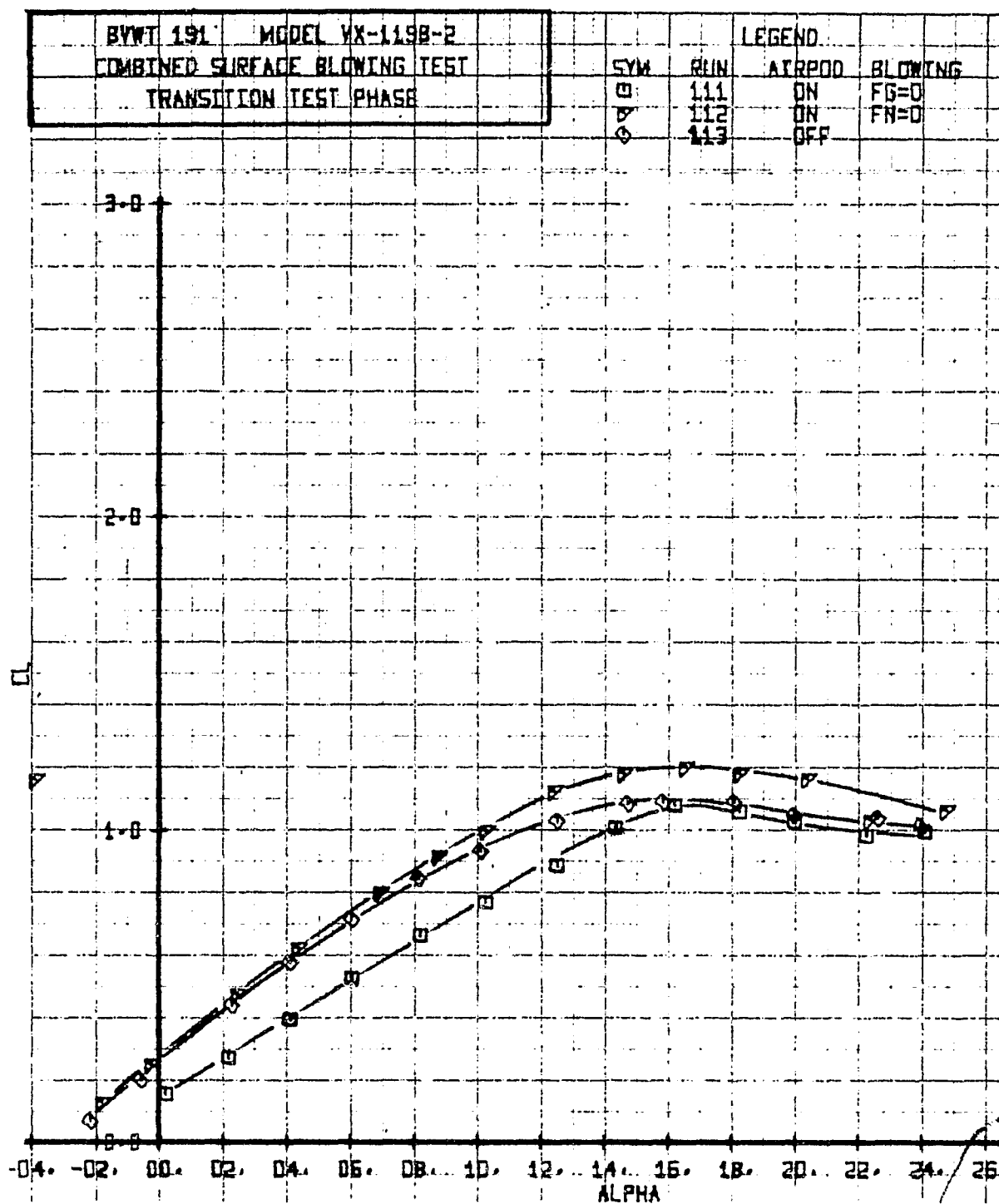


Figure 7.3-2. Extended Wing, Effect of Air Pod with Clean Wing
a. $C_L - \alpha$

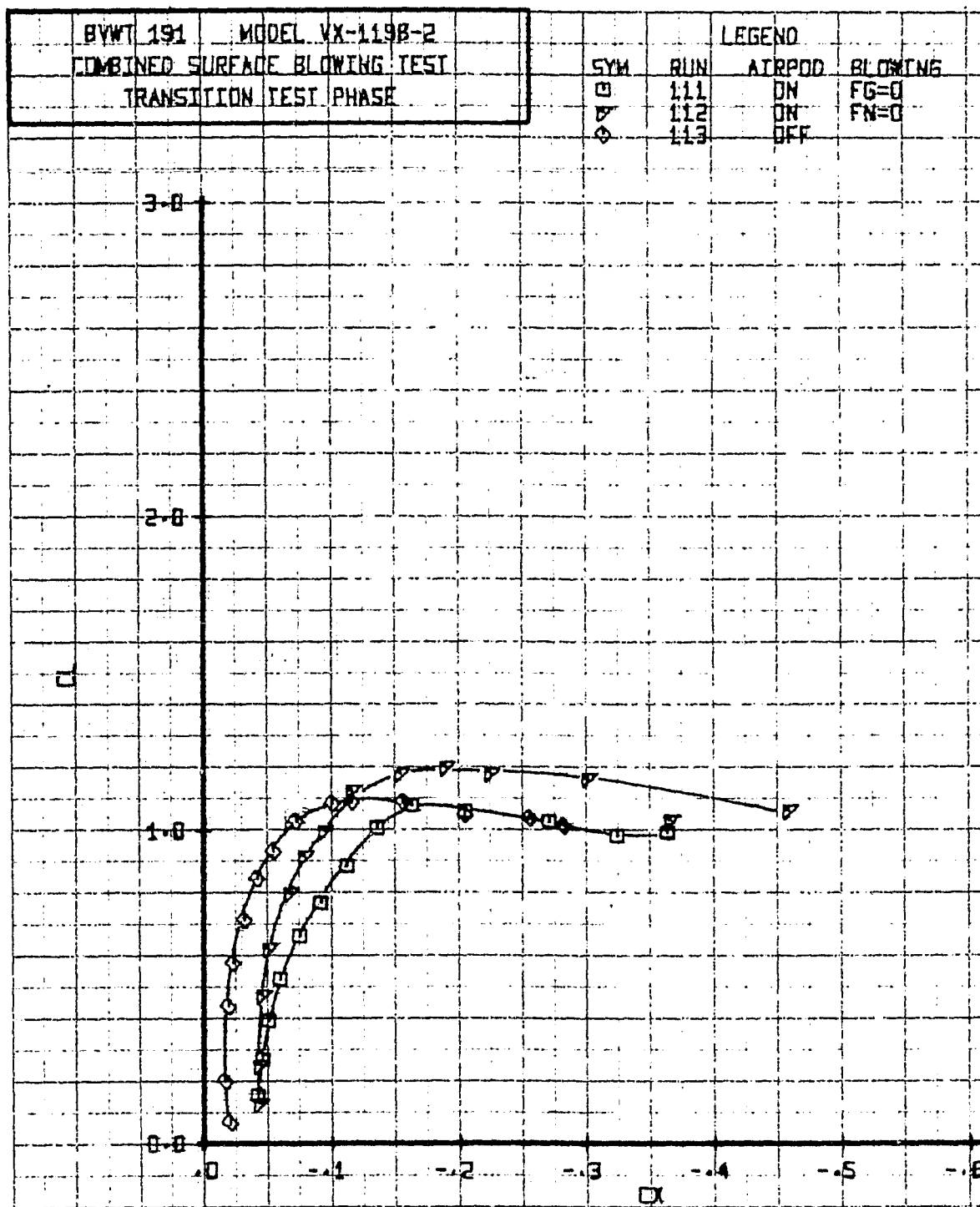


Figure 7.3-2. Extended Wing, Effect of Air Pod with Clean Wing
b. $C_L - C_X$

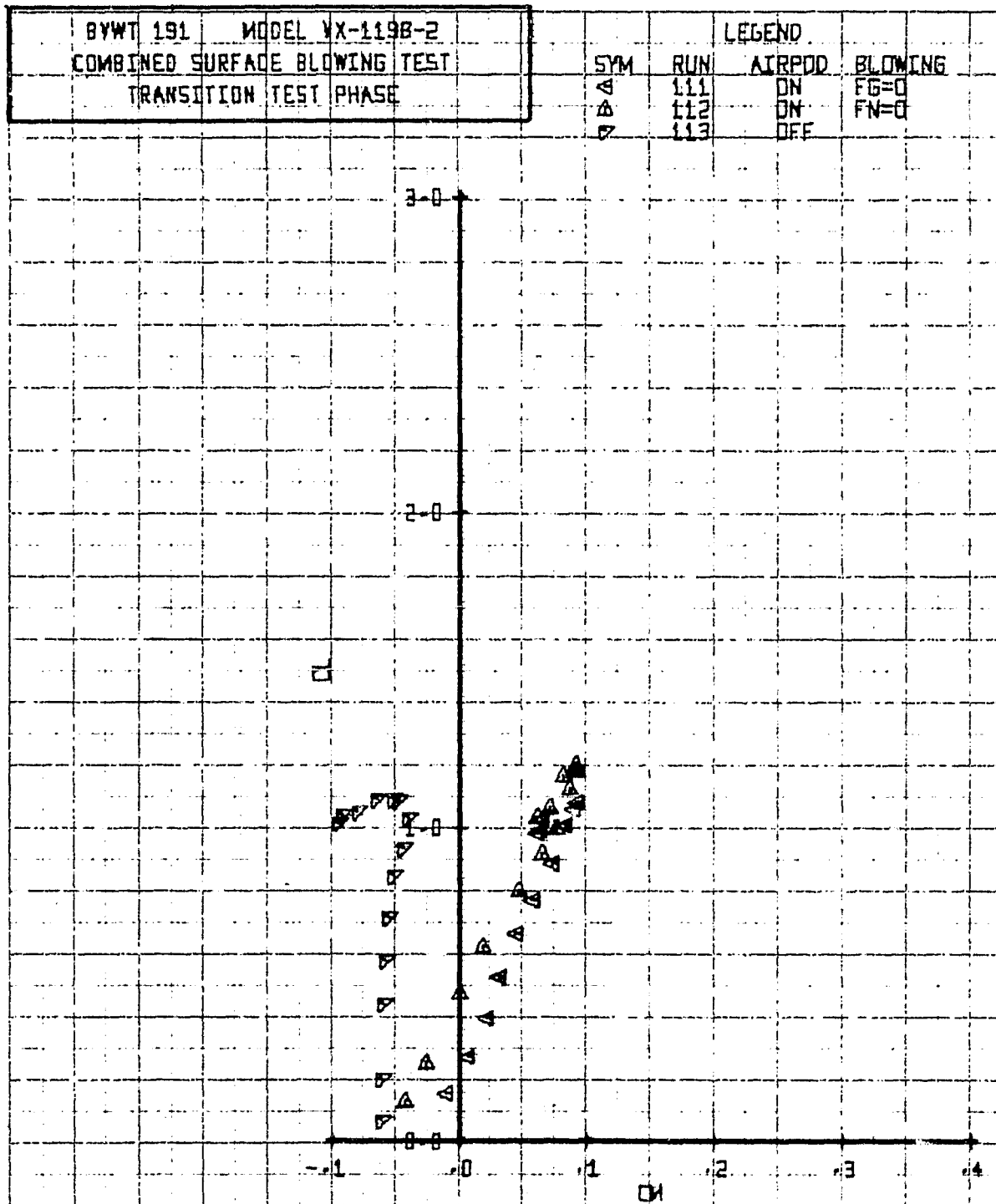


Figure 7.3-2. Extended Wing, Effect of Air Pod with Clean Wing
c. $C_L - C_m$

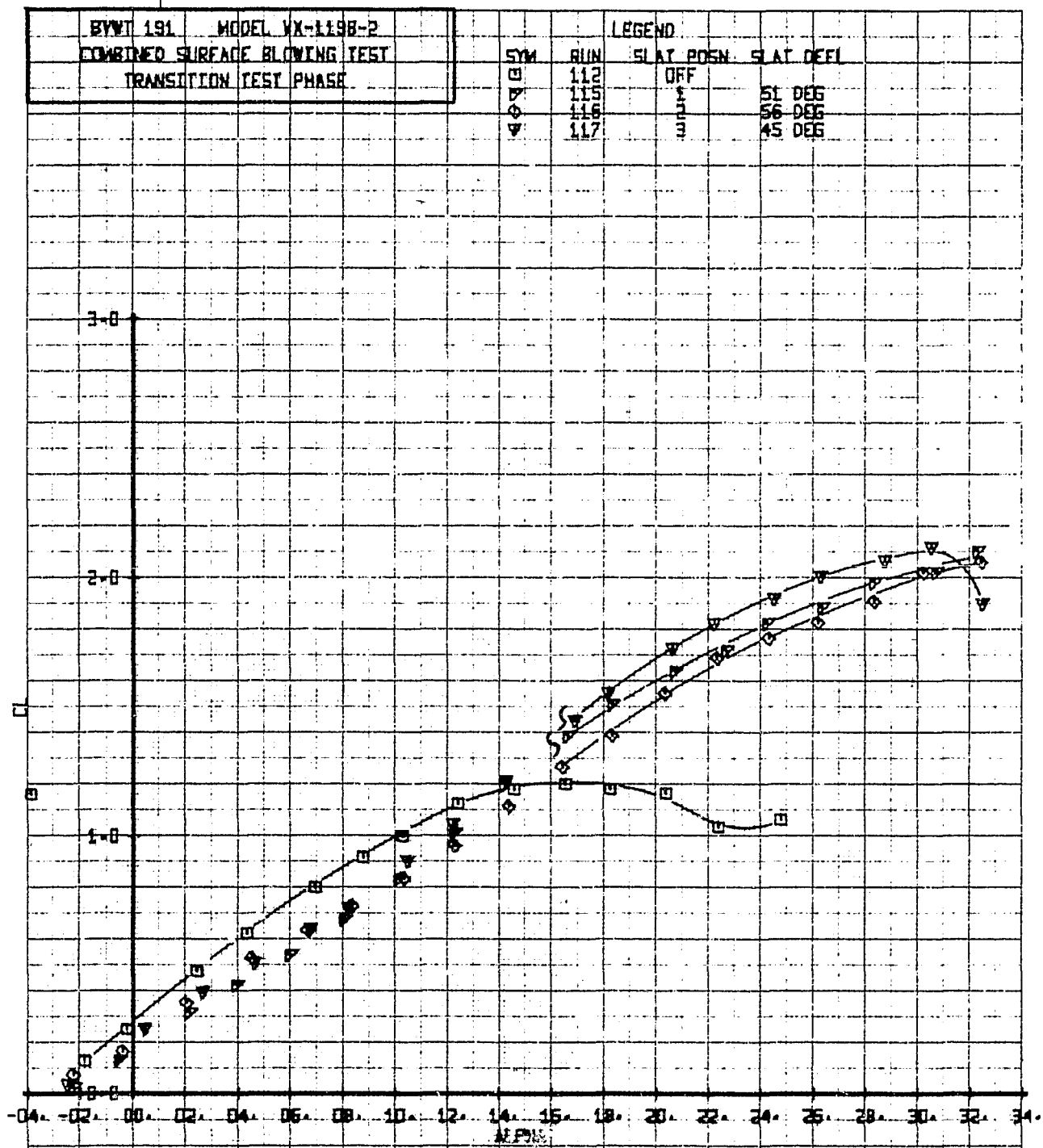


Figure 7.3-3. Extended Wing, Slat Effectiveness, Flaps Retracted, Power Off

a. $C_L - \alpha$

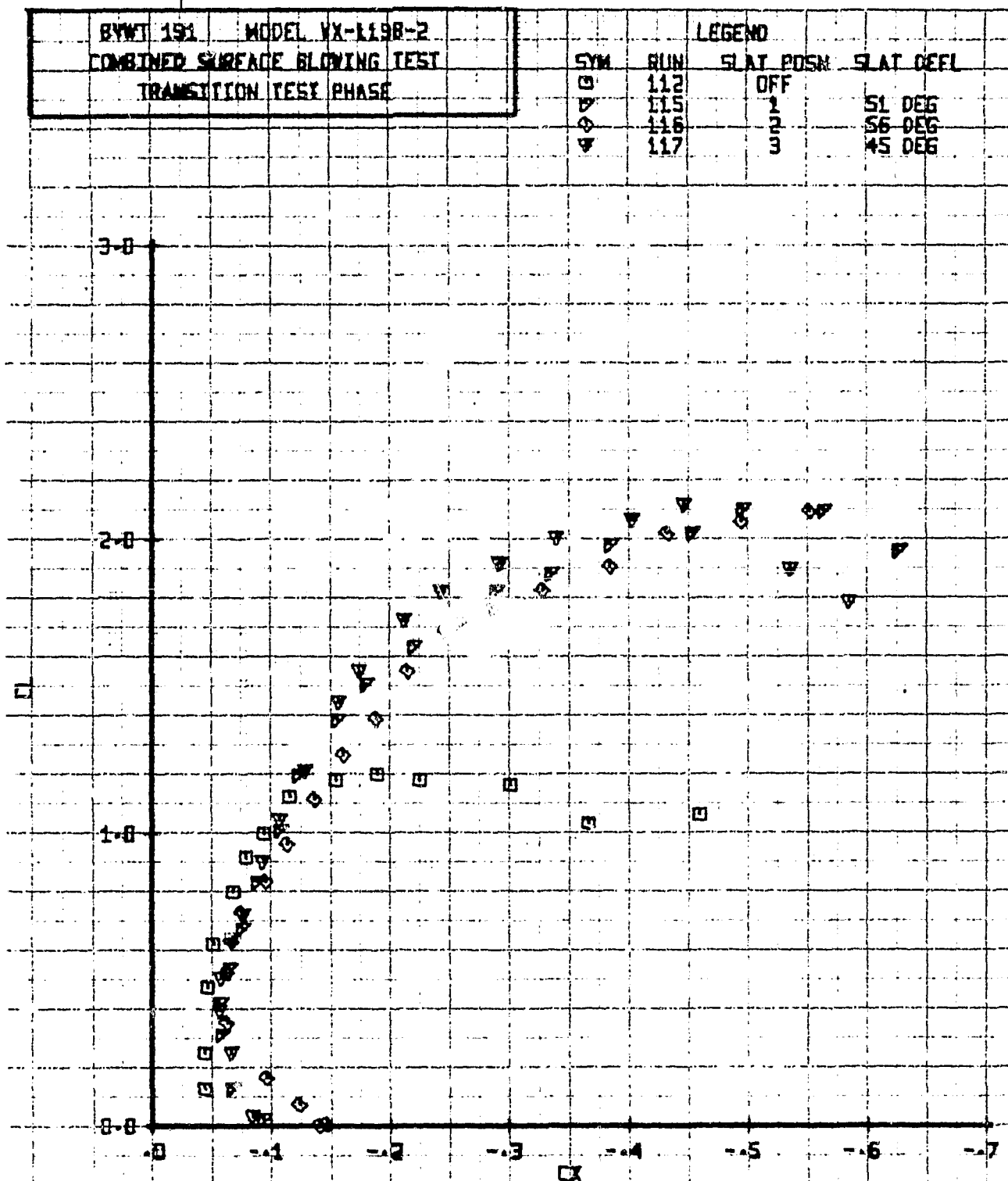


Figure 7.3-3. Extended Wing, Slat Effectiveness, Flaps Retracted, Power Off
 b. $C_L - C_X$

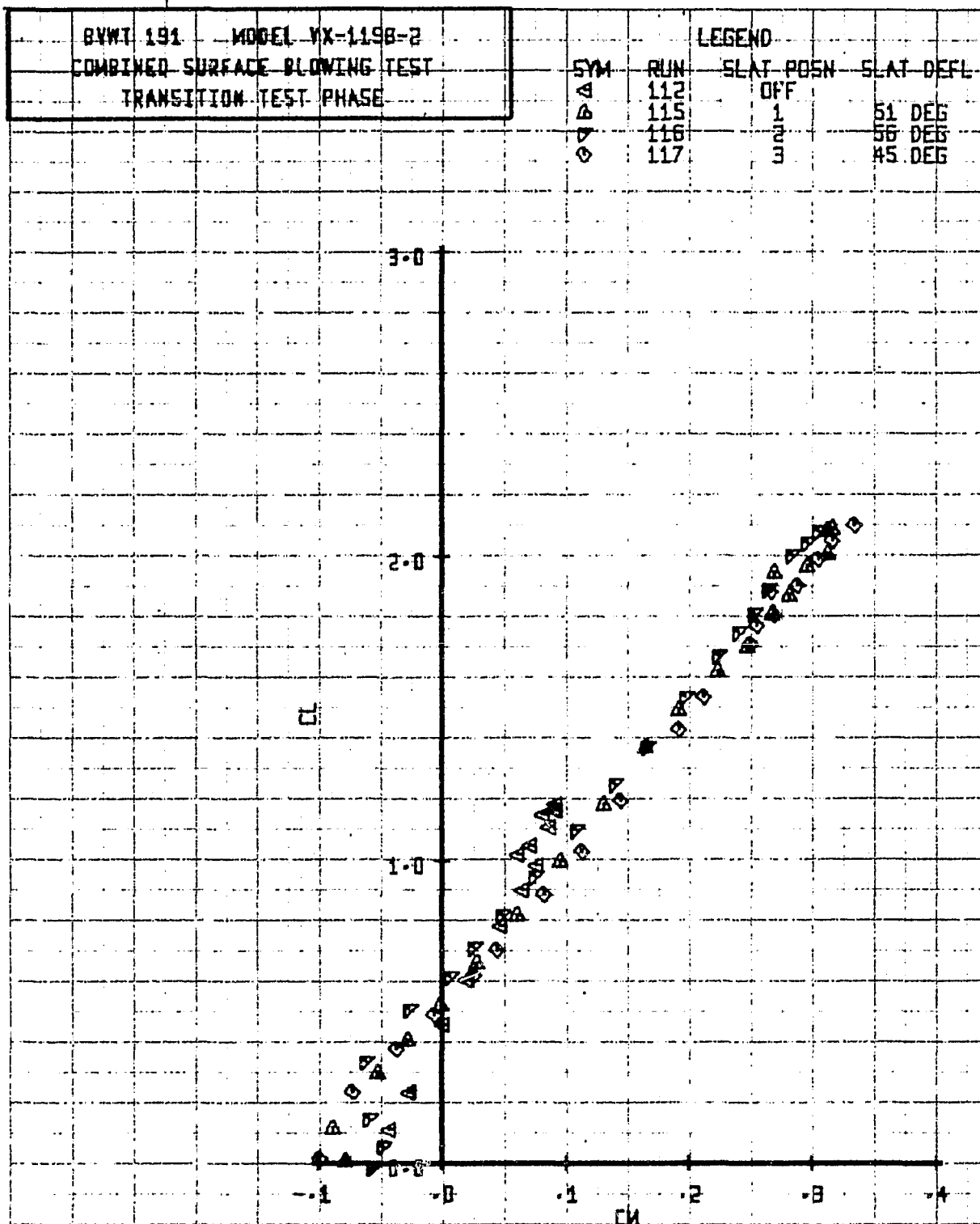


Figure 7.3-3. Extended Wing, Slat Effectiveness, Flaps Retracted, Power Off
c. $C_L - C_m$

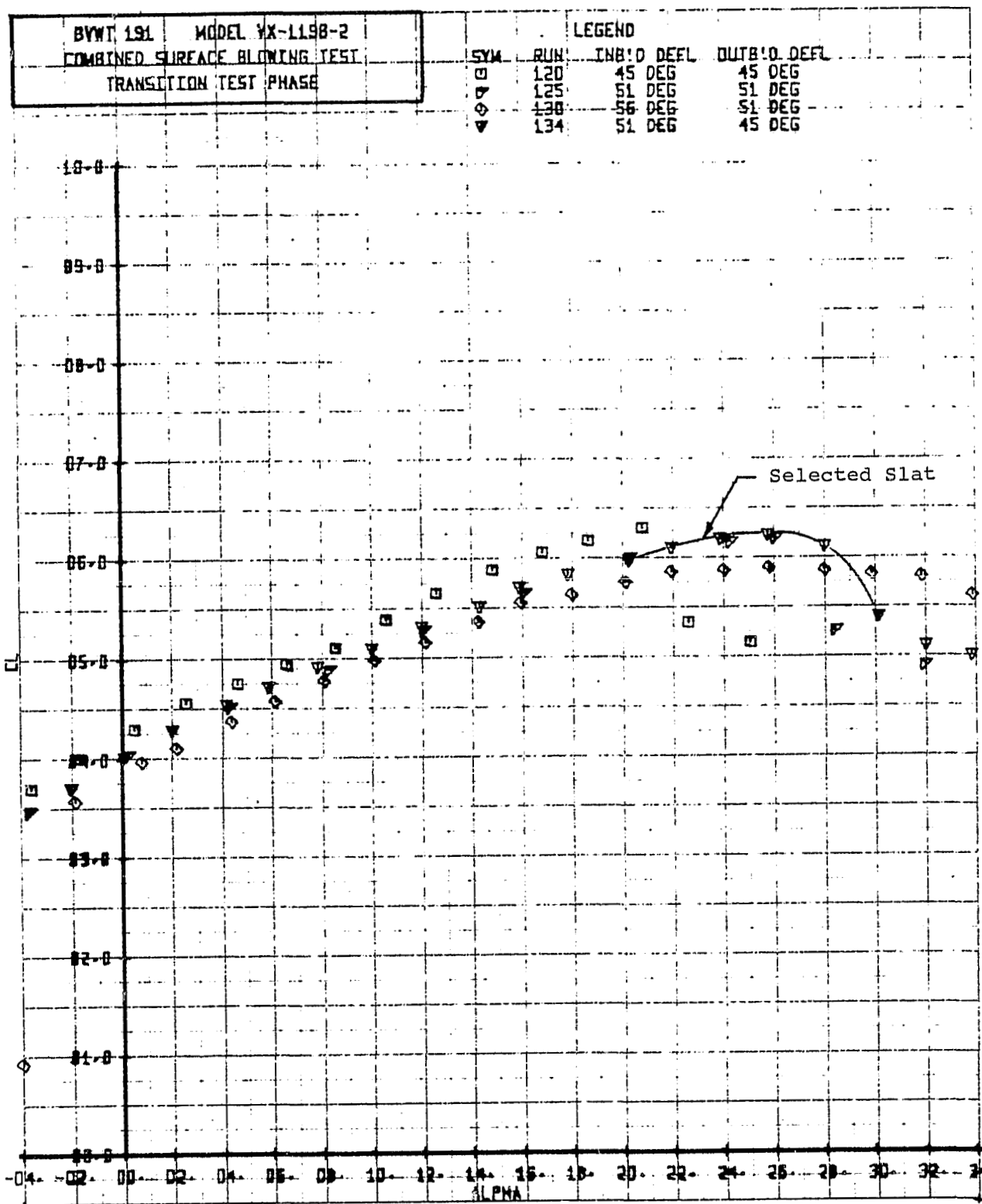


Figure 7.3-4. Extended Wing, Slat Effectiveness, $\delta_f = 45^\circ$, $C_j = 2$.
a. $C_L - \alpha$

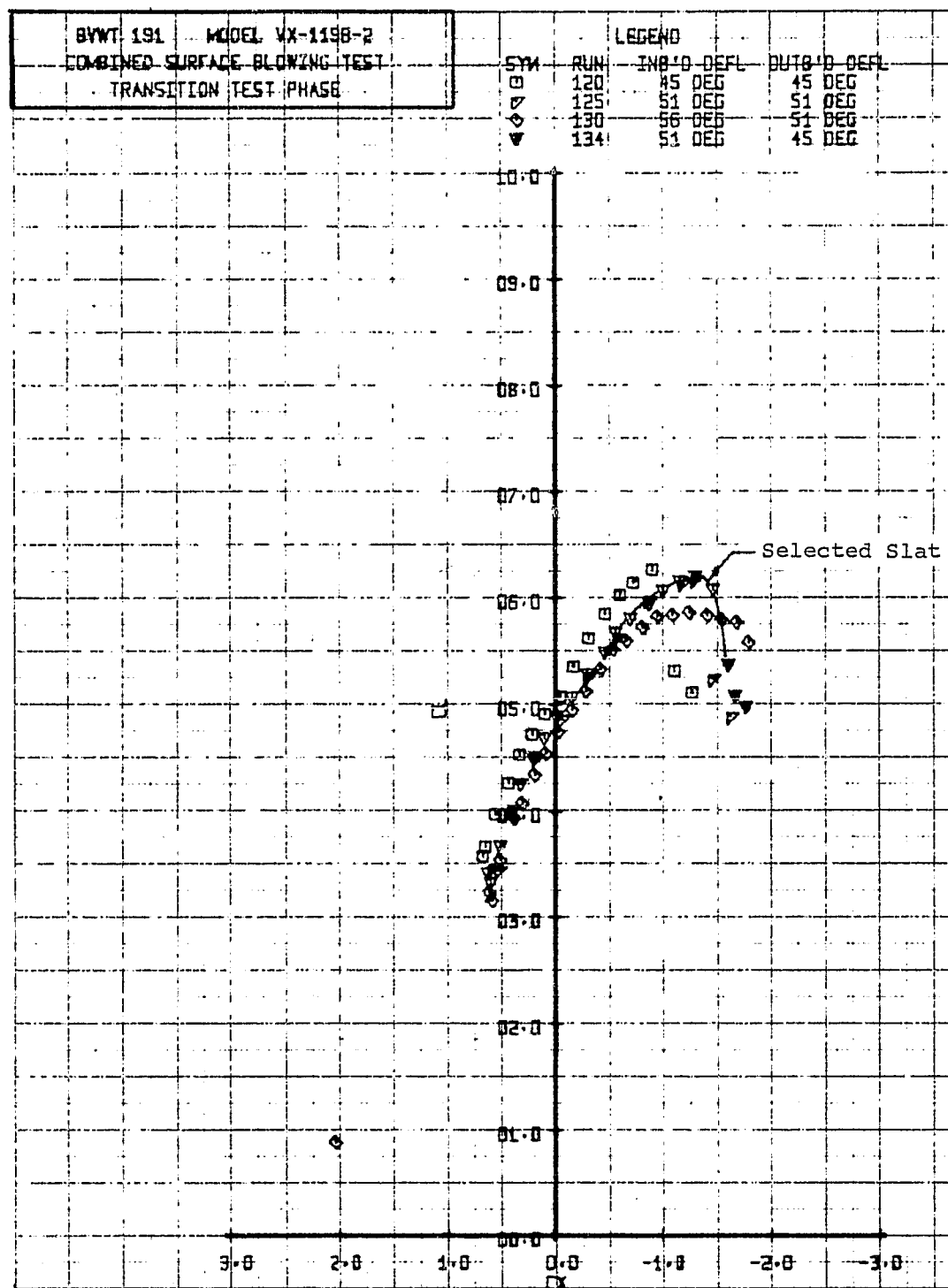


Figure 7.3-4. Extended Wing, Slat Effectiveness, $\delta_f = 45^\circ$, $C_j = 2$,
b. $C_L - C_X$

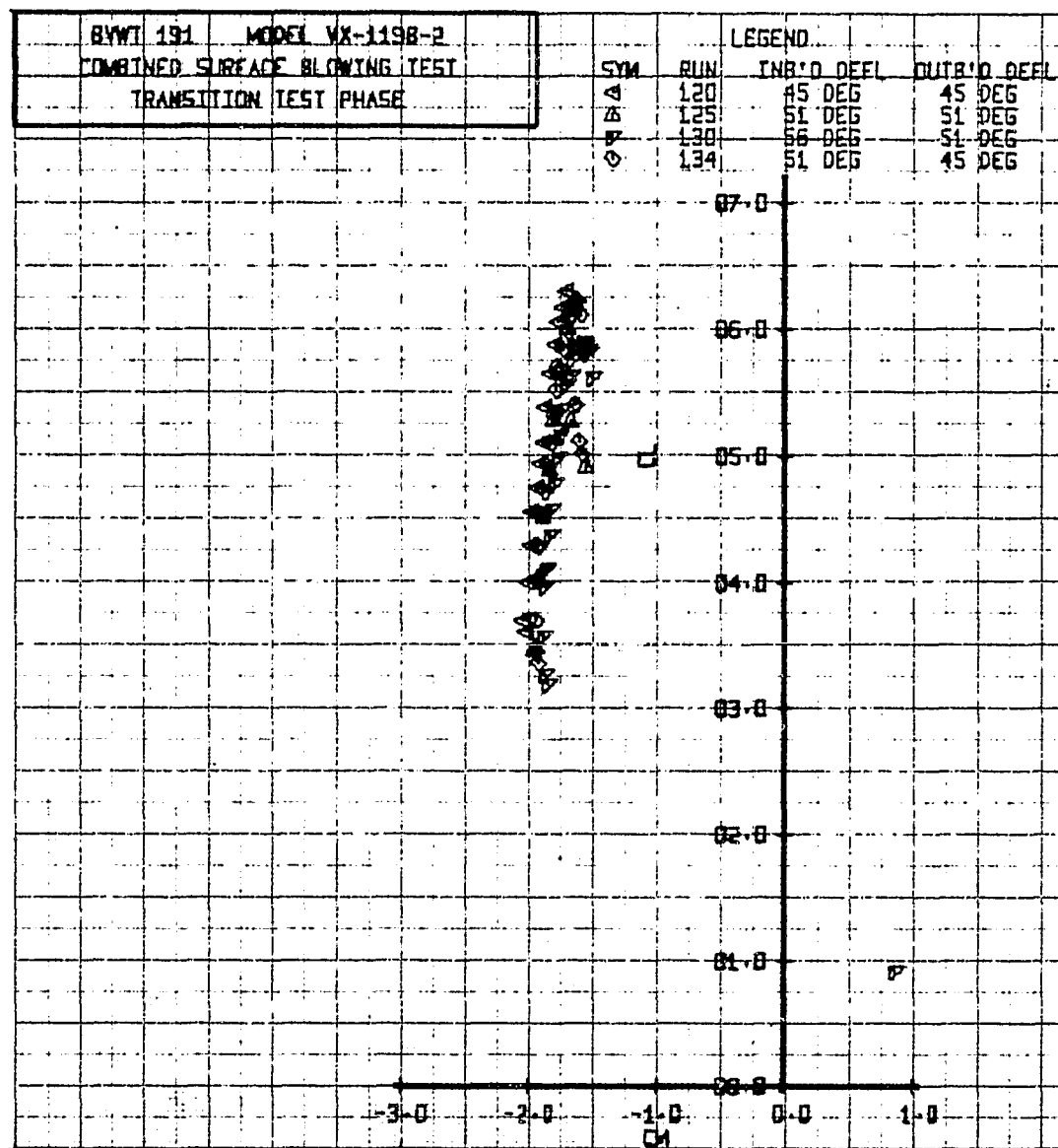


Figure 7.3-4. Extended Wing, Slat Effectiveness, $\delta_f = 45^\circ$, $C_j = 2$,
c. $C_L - C_m$

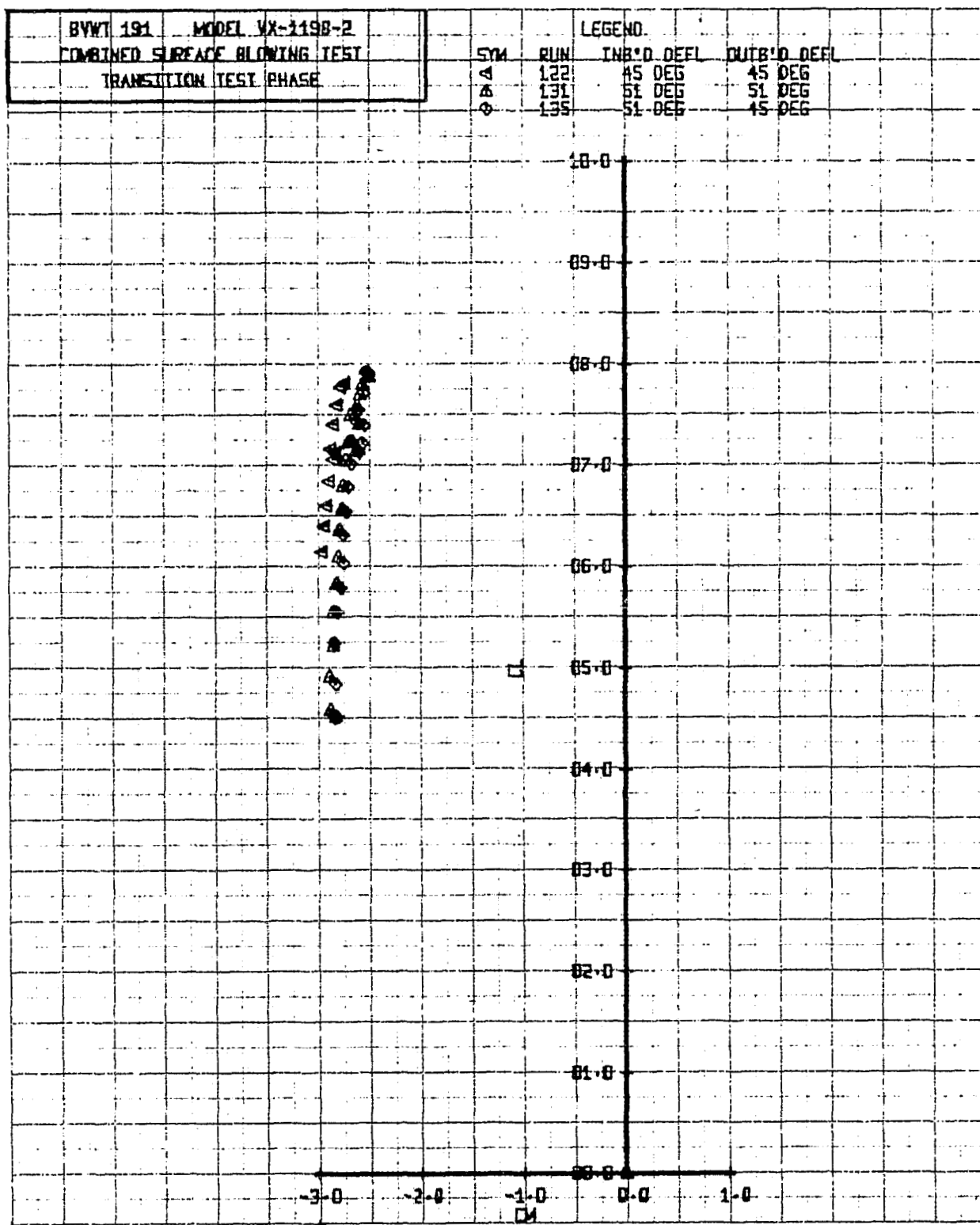


Figure 7.3-5. Extended Wing, Slat Effectiveness, $\delta_f = 45^\circ$, $C_j = 4$,
a. $C_L - \alpha$

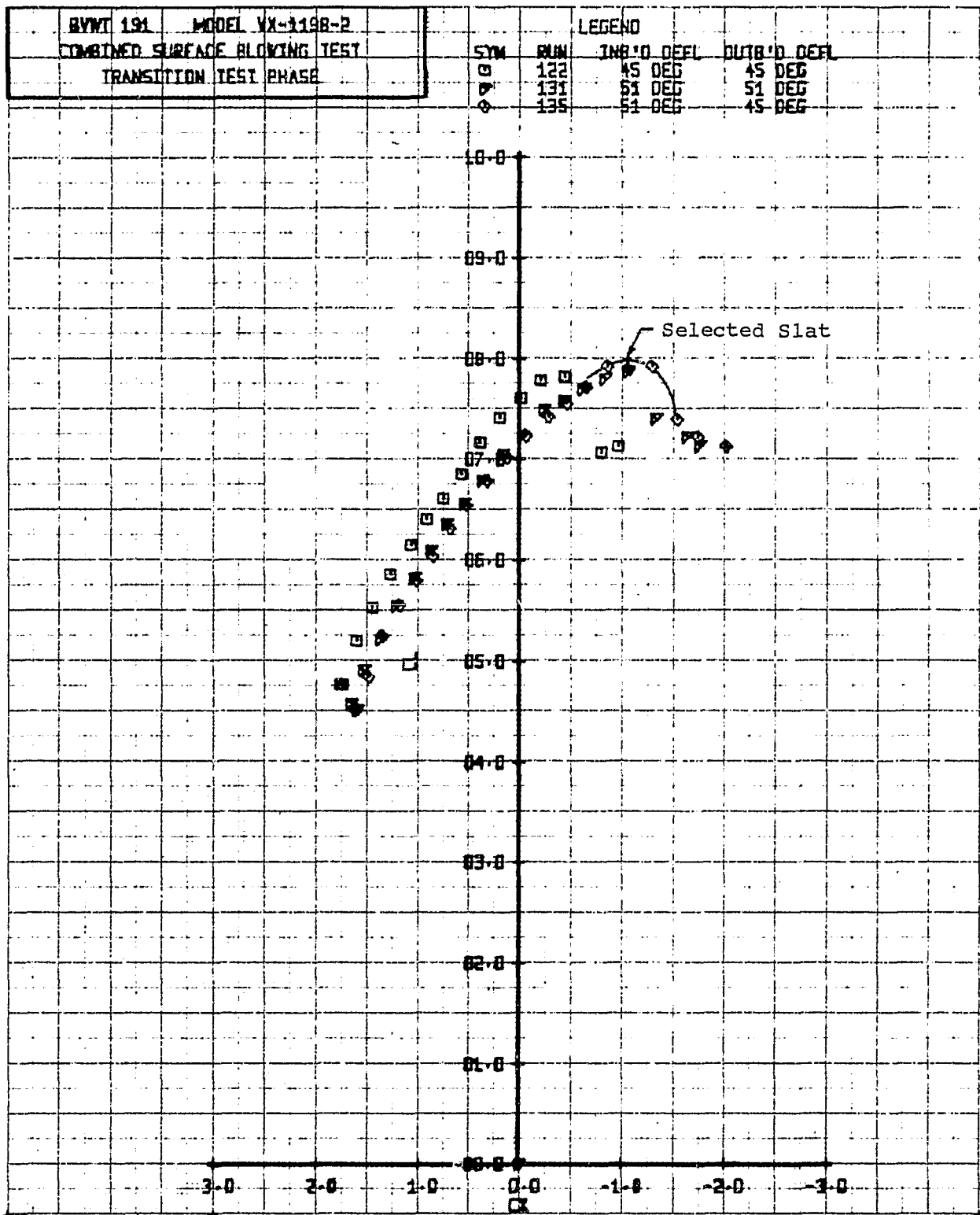


Figure 7.3-5. Extended Wing, Slat Effectiveness, $\delta_f = 45^\circ$, $C_j = 4$.
b. $C_L - C_X$

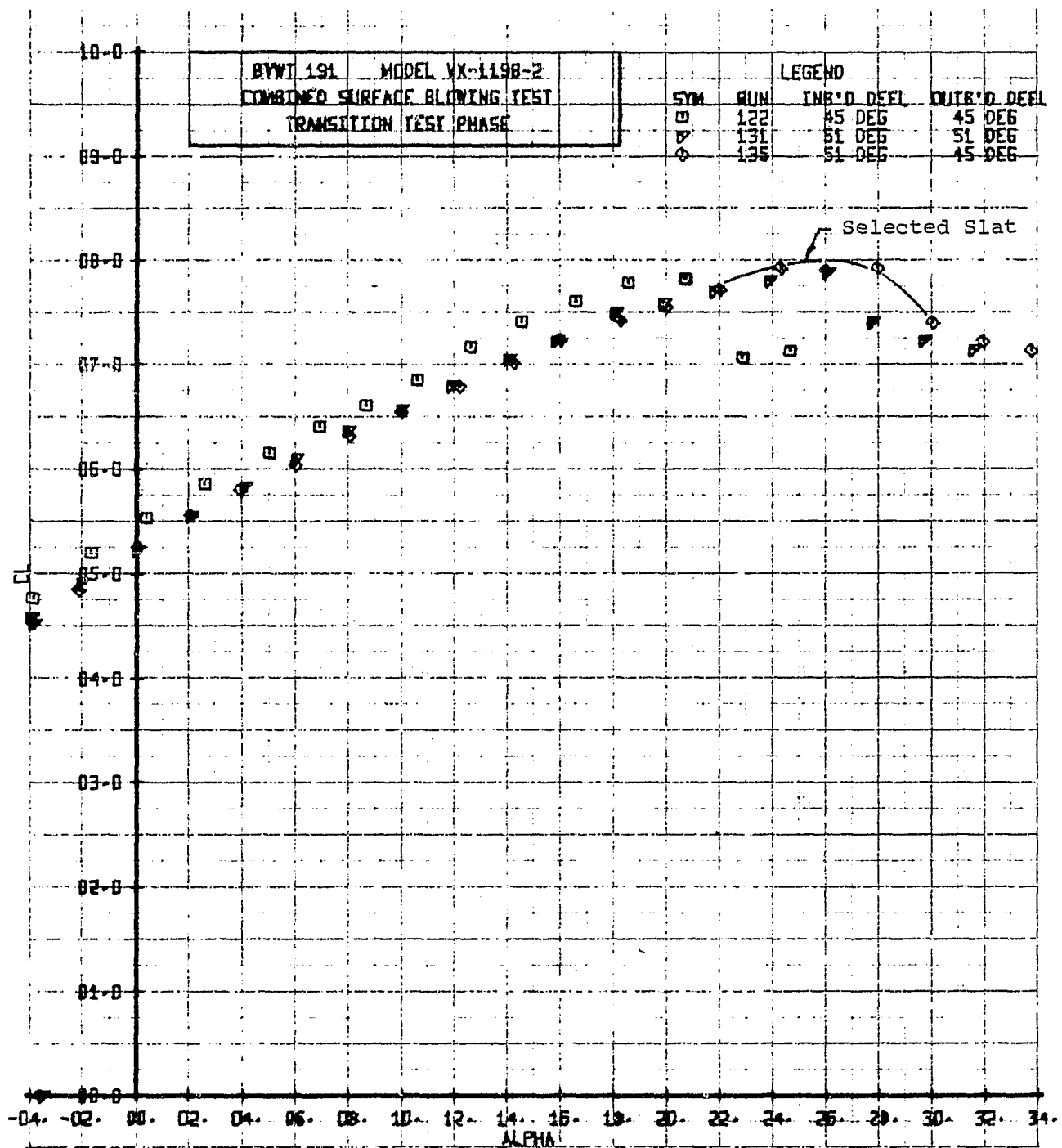
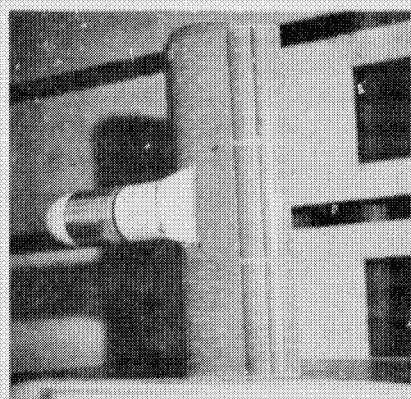
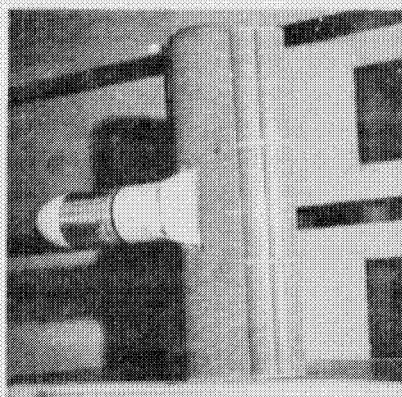


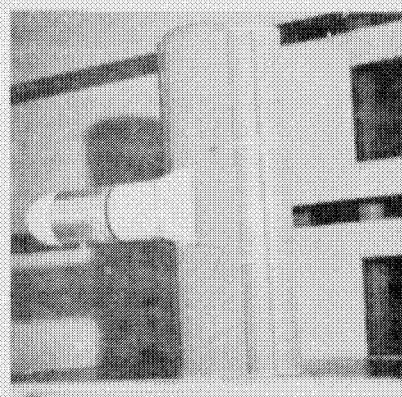
Figure 7.3-5. Extended Wing, Slat Effectiveness, $\delta_f = 45^\circ$, $C_j = 4$,
c. $C_L - C_m$



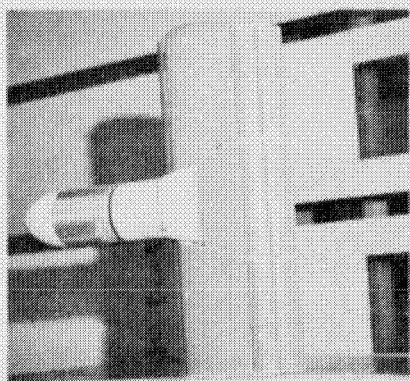
189593 a: $\alpha_W = 4^\circ$ 5-1



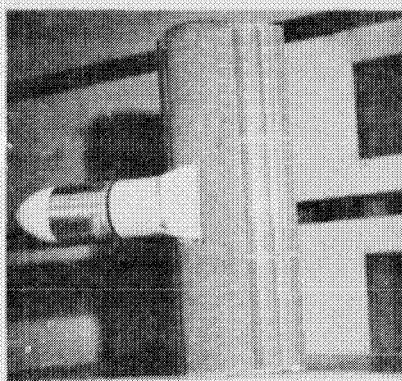
b: $\alpha_W = 9^\circ$ 5-2



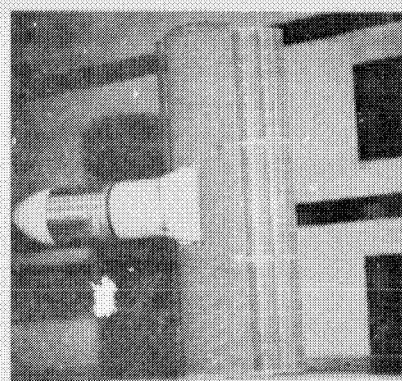
c: $\alpha_W = 12^\circ$ 5-3



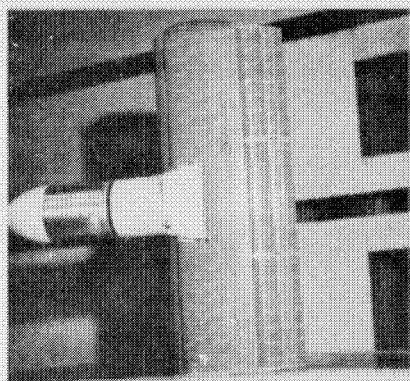
d: $\alpha_W = 14^\circ$ 5-4



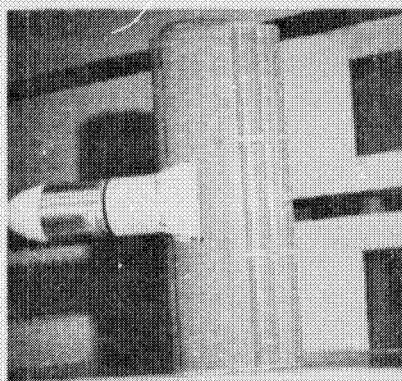
e: $\alpha_W = 18.4^\circ$ 5-5



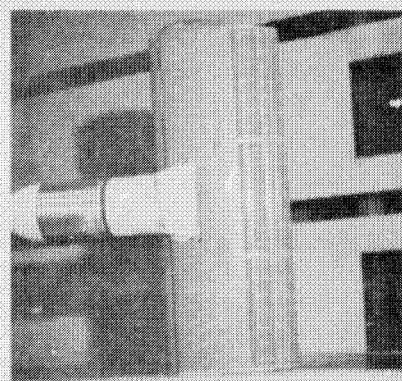
f: $\alpha_W = 20.6^\circ$ 5-6



g: $\alpha_W = 25.2^\circ$ 5-7

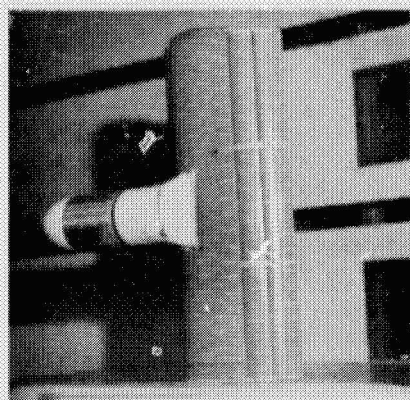


h: $\alpha_W = 27.0^\circ$ 5-8



i: $\alpha_W = 28.0^\circ$ 5-9

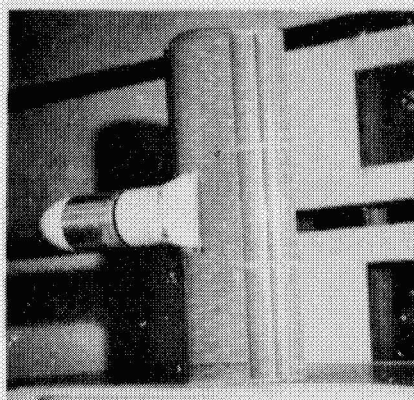
Figure 7.3-6. Extended-Wing Airflow, $\delta_f = 45^\circ$, $C_f = 2$



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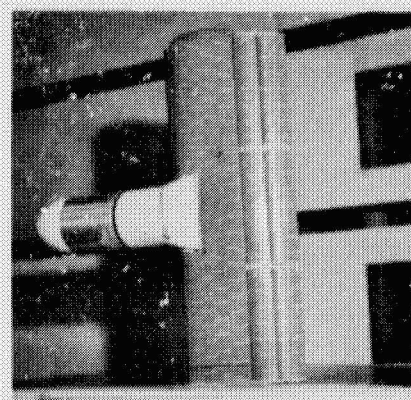
a: $\alpha_W = 4^\circ$

12



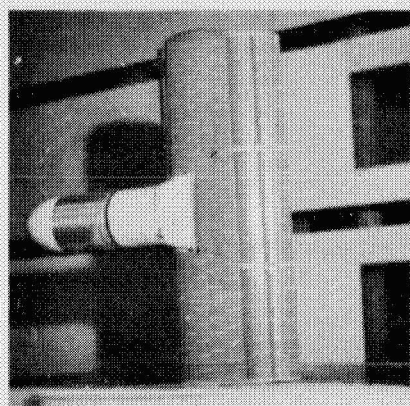
b: $\alpha_W = 6^\circ$

13



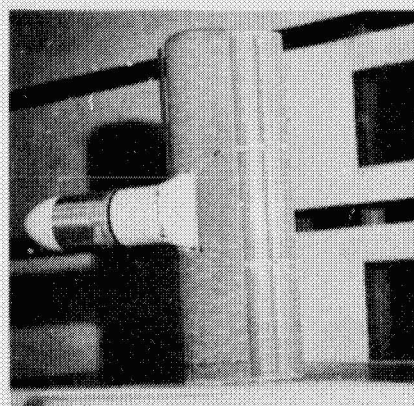
c: $\alpha_W = 7.9^\circ$

14



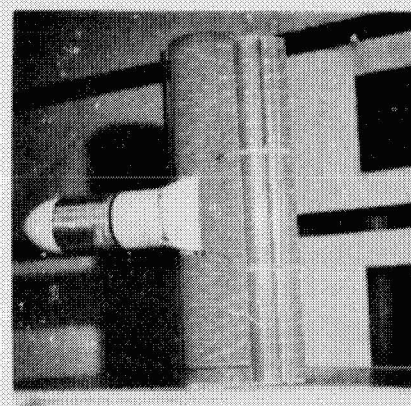
d: $\alpha_W = 10.2^\circ$

15



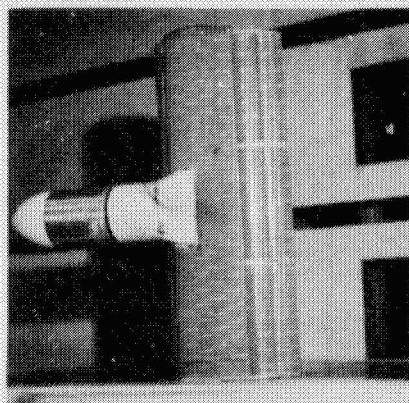
e: $\alpha_W = 12.0^\circ$

16



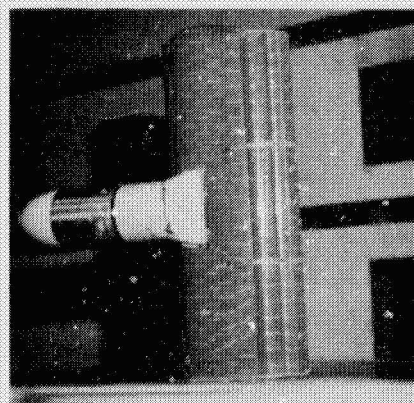
f: $\alpha_W = 14.2^\circ$

17



g: $\alpha_W = 16.0^\circ$

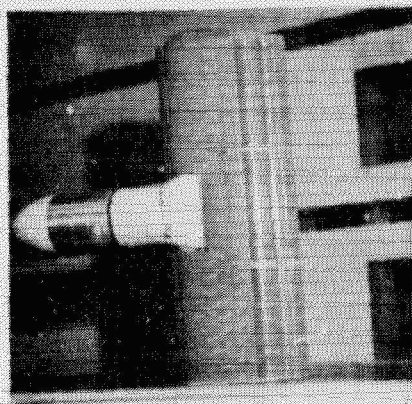
18



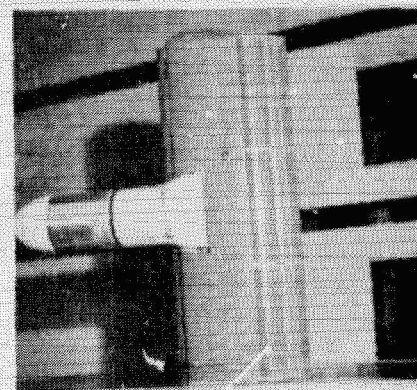
h: $\alpha_W = 18.0^\circ$

19

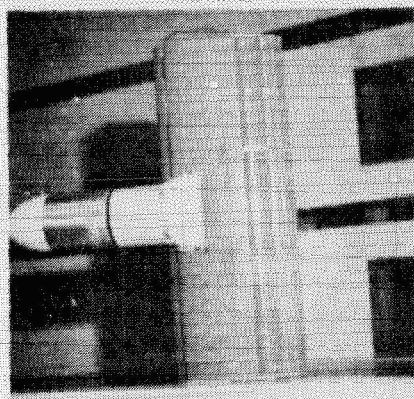
Figure 7.3—7. Extended-Wing Airflow (Fence Added), $\delta_f = 45^\circ$, $C_f = 2$



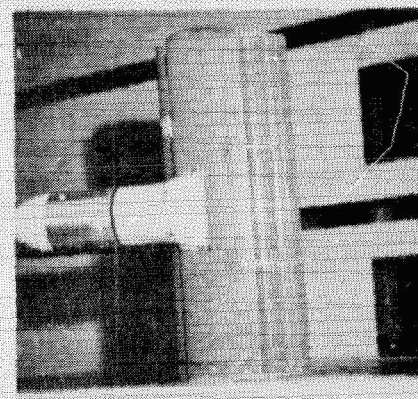
i: $\alpha_W = 19.9^\circ$ 20



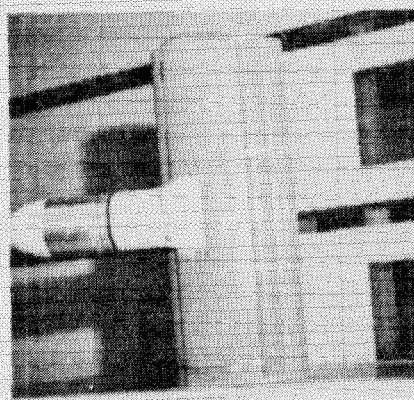
j: $\alpha_W = 22.0^\circ$ 21



k: $\alpha_W = 24.0^\circ$ 22



l: $\alpha_W = 26.4^\circ$ 23



m: $\alpha_W = 27.0^\circ$ 24

Figure 7.3-7. (Continued): Extended Wing Airflow (Fence Added), $\delta_f = 45^\circ$, $C_j = 2$

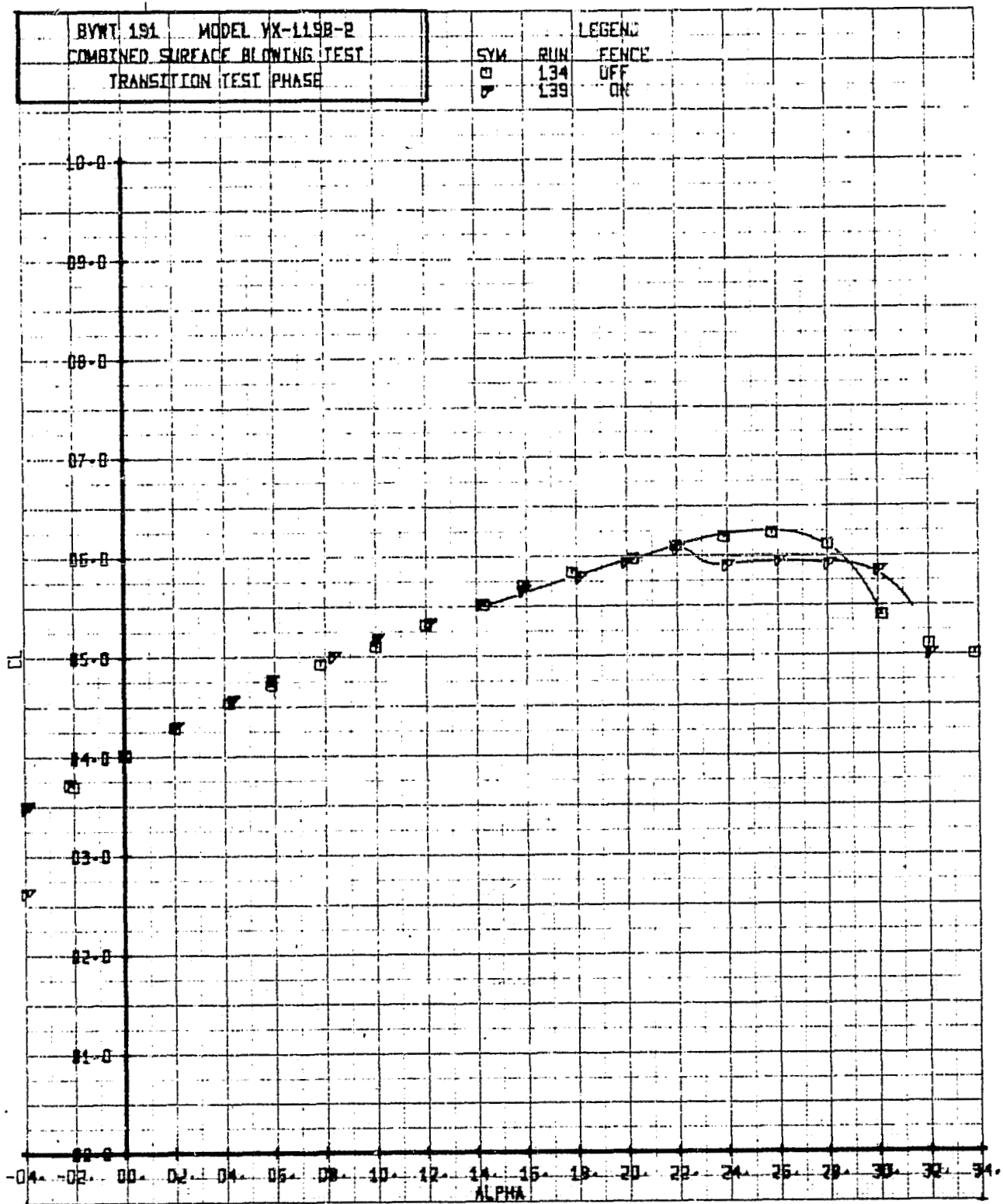


Figure 7.3--8. Extended Wing, Effect of Fence
a. $C_L - \alpha$

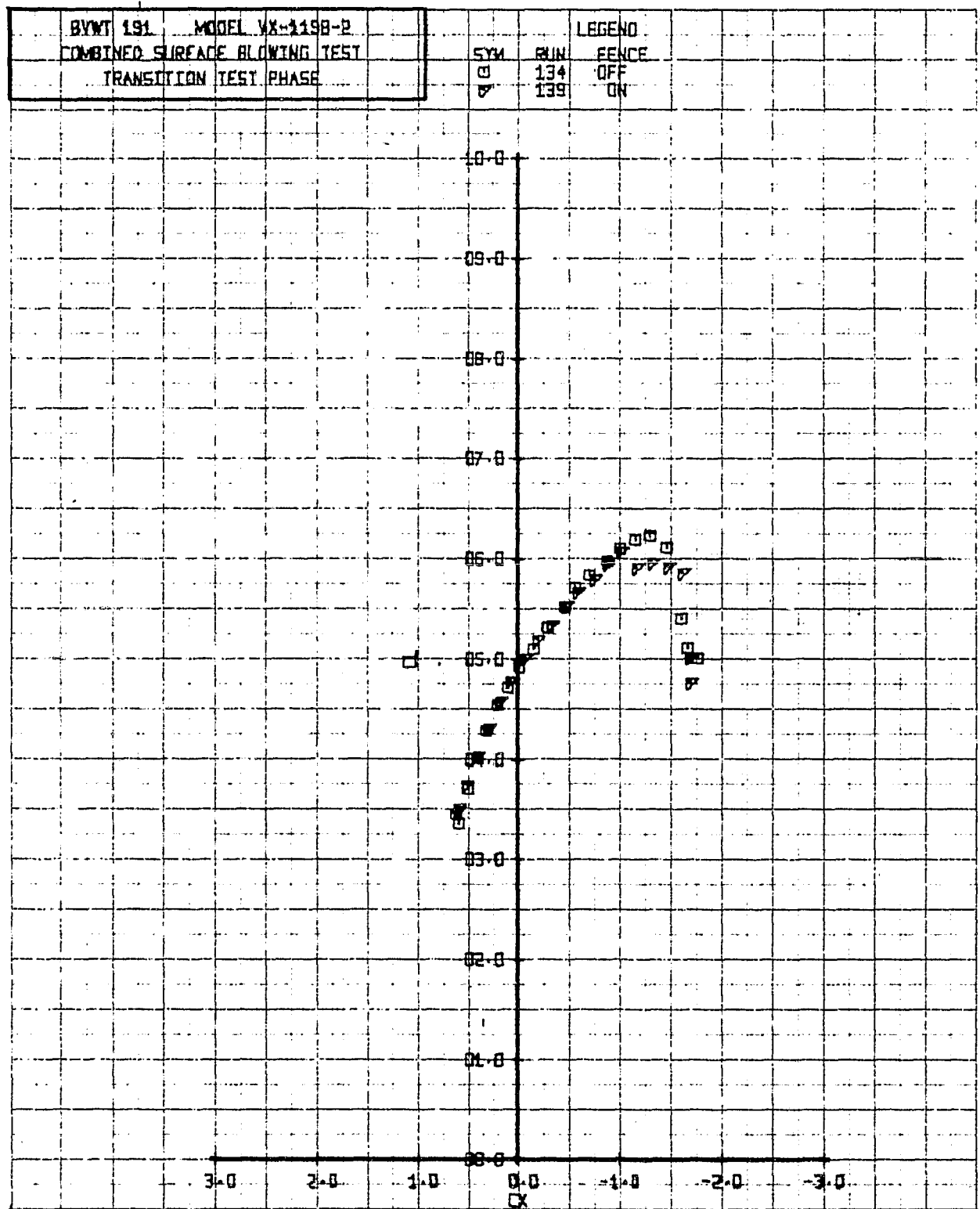


Figure 7.3-8. Extended Wing, Effect of Fence
b. $C_L - C_X$

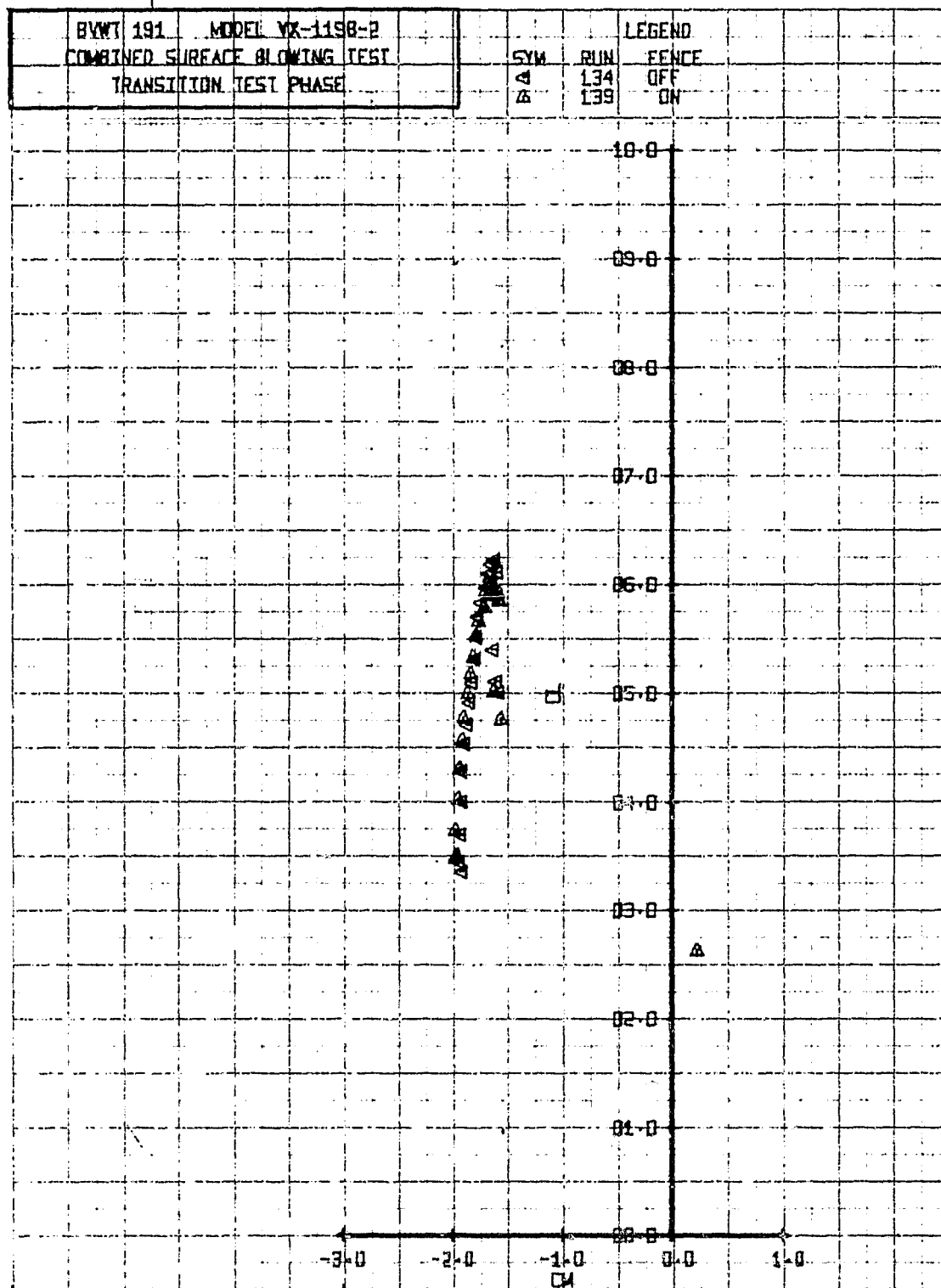


Figure 7.3-8. Extended Wing, Effect of Fence
c. $C_L - C_m$

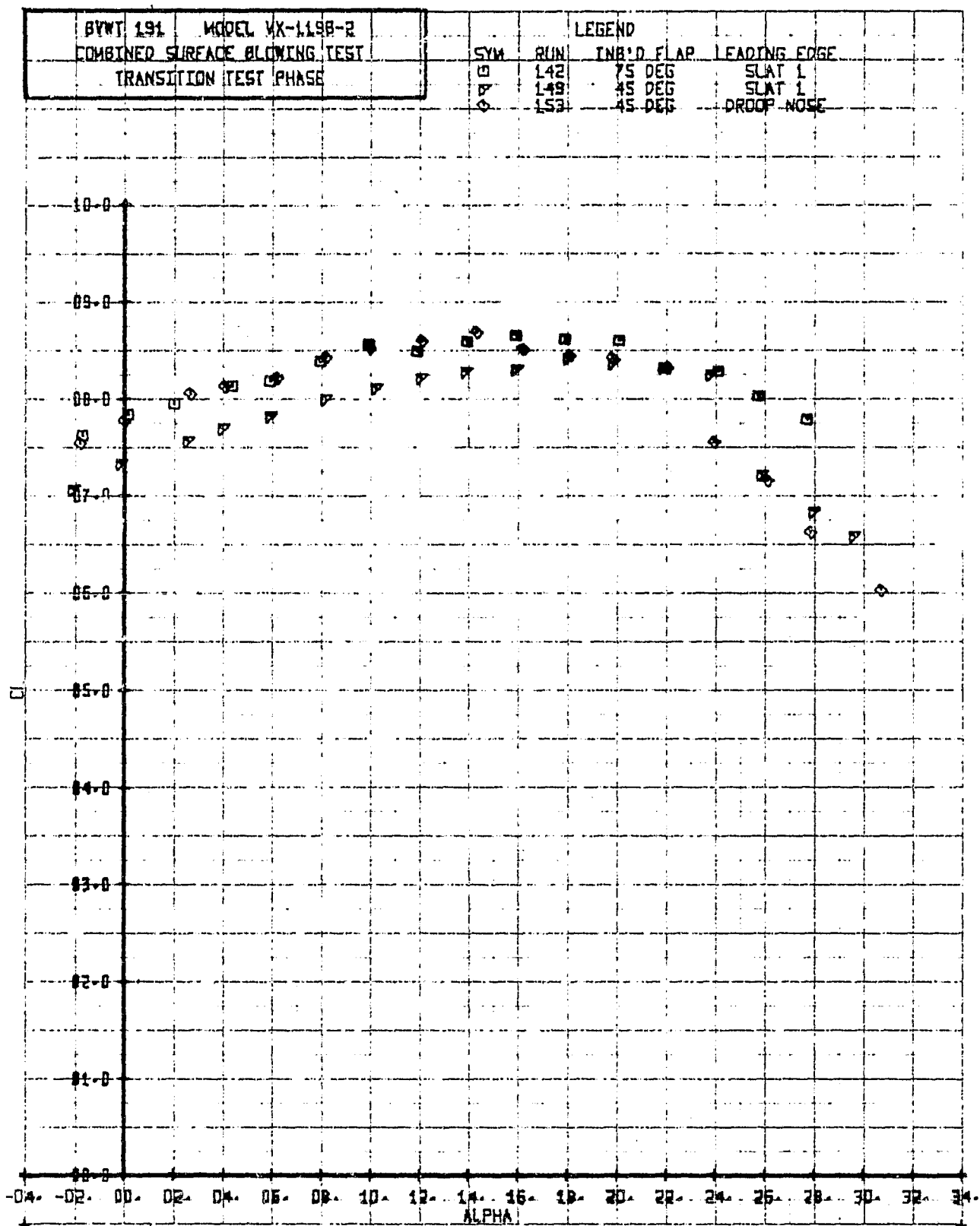


Figure 7.3-9. Extended Wing, Effect of Reduced Inboard-Flap Deflection at $C_j = 4$
a. $C_L - \alpha$

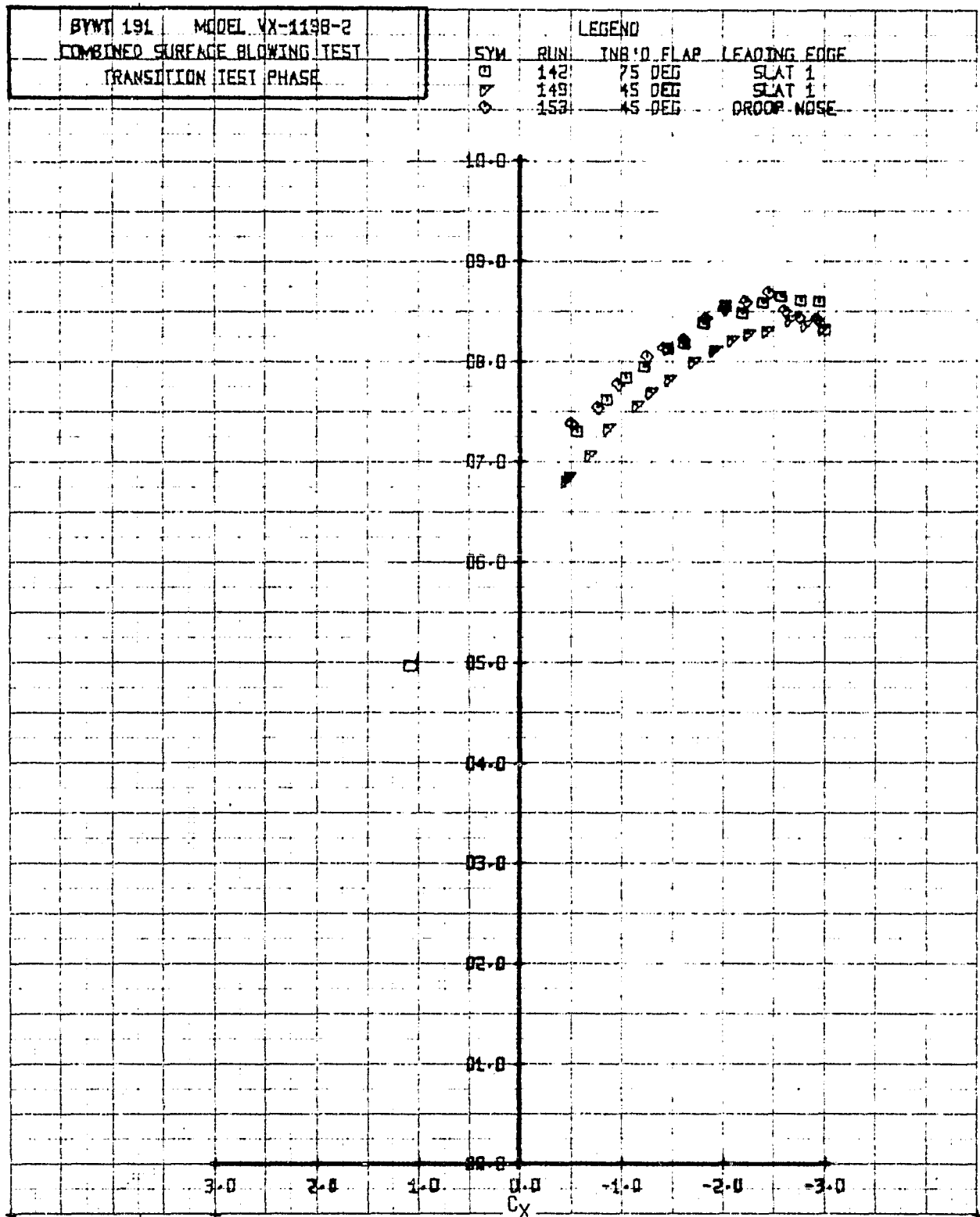


Figure 7.3-9. Extended Wing, Effect of Reduced Inboard-Flap Deflection at $C_j = 4$

b. $C_L - C_X$

BWWT 191 MODEL VX-119B-2		LEGEND		
COMBINED SURFACE BLOWING TEST		SYM	RUN	INB'D FLAP LEADING EDGE
TRANSITION TEST PHASE		□	142	75 DEG SLAT 1
		◇	149	45 DEG SLAT 1
		◇	153	45 DEG DROOP NOSE

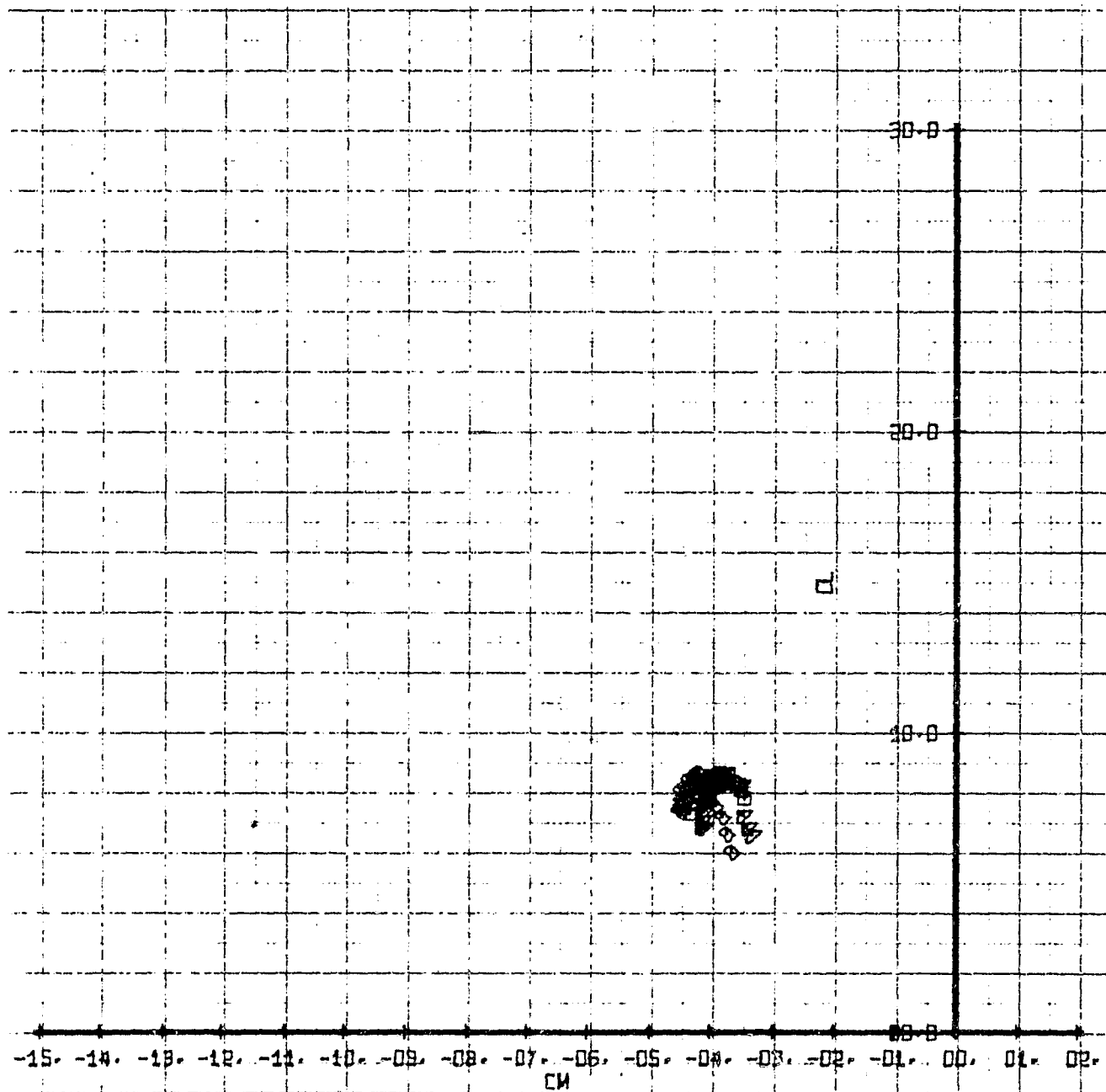


Figure 7.3-9. Extended Wing, Effect of Reduced Inboard-Flap Deflection at $C_j = 4$
c. $C_L - C_m$

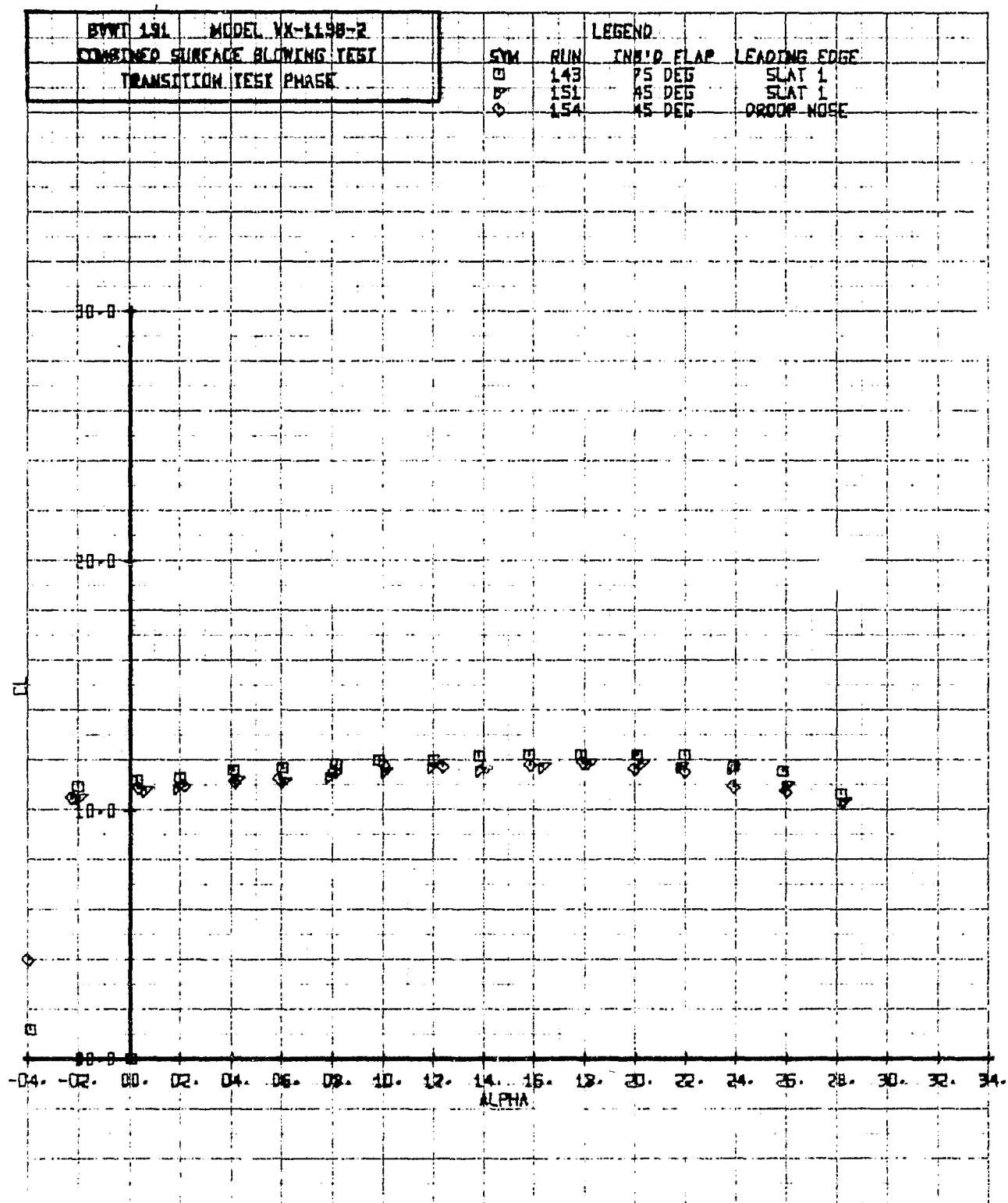


Figure 7.3-10. Extended Wing, Effect of Reduced Inboard-Flap Deflection at $C_j = 8$

a. $C_L - \alpha$

8VWT 191	MODEL VX-119B-2		
COMBINED SURFACE BLOWING TEST			
TRANSITION TEST PHASE			
		LEGEND	
SYM	RUN	INB'D FLAP	LEADING EDGE
□	143	75 DEG	SLAT 1
▽	151	45 DEG	SLAT 1
◇	154	45 DEG	DROOP NOSE

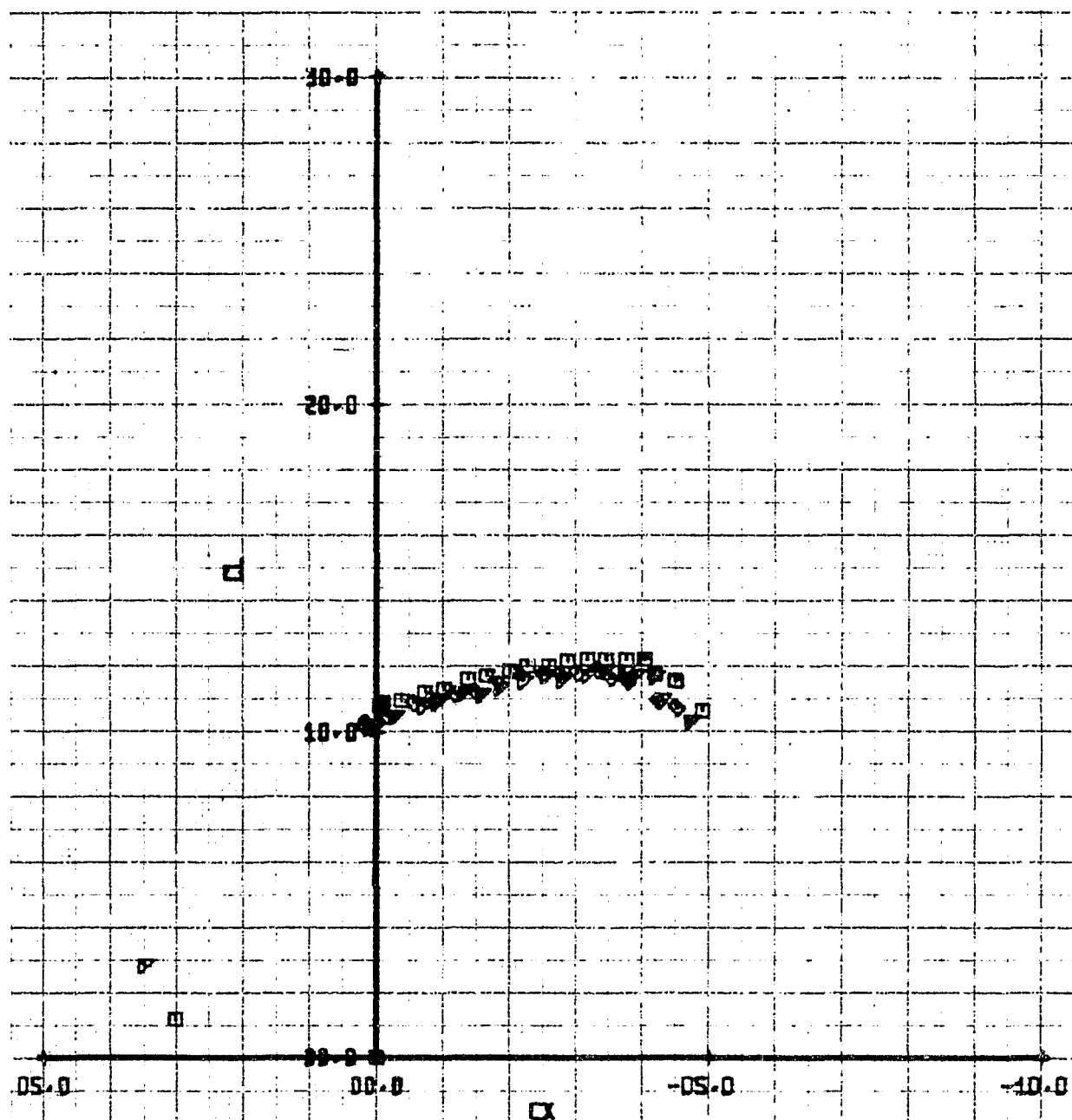


Figure 7.3-10. Extended Wing, Effect of Reduced Inboard-Flap Deflection at $C_j = 8$
b. $C_L - C_X$

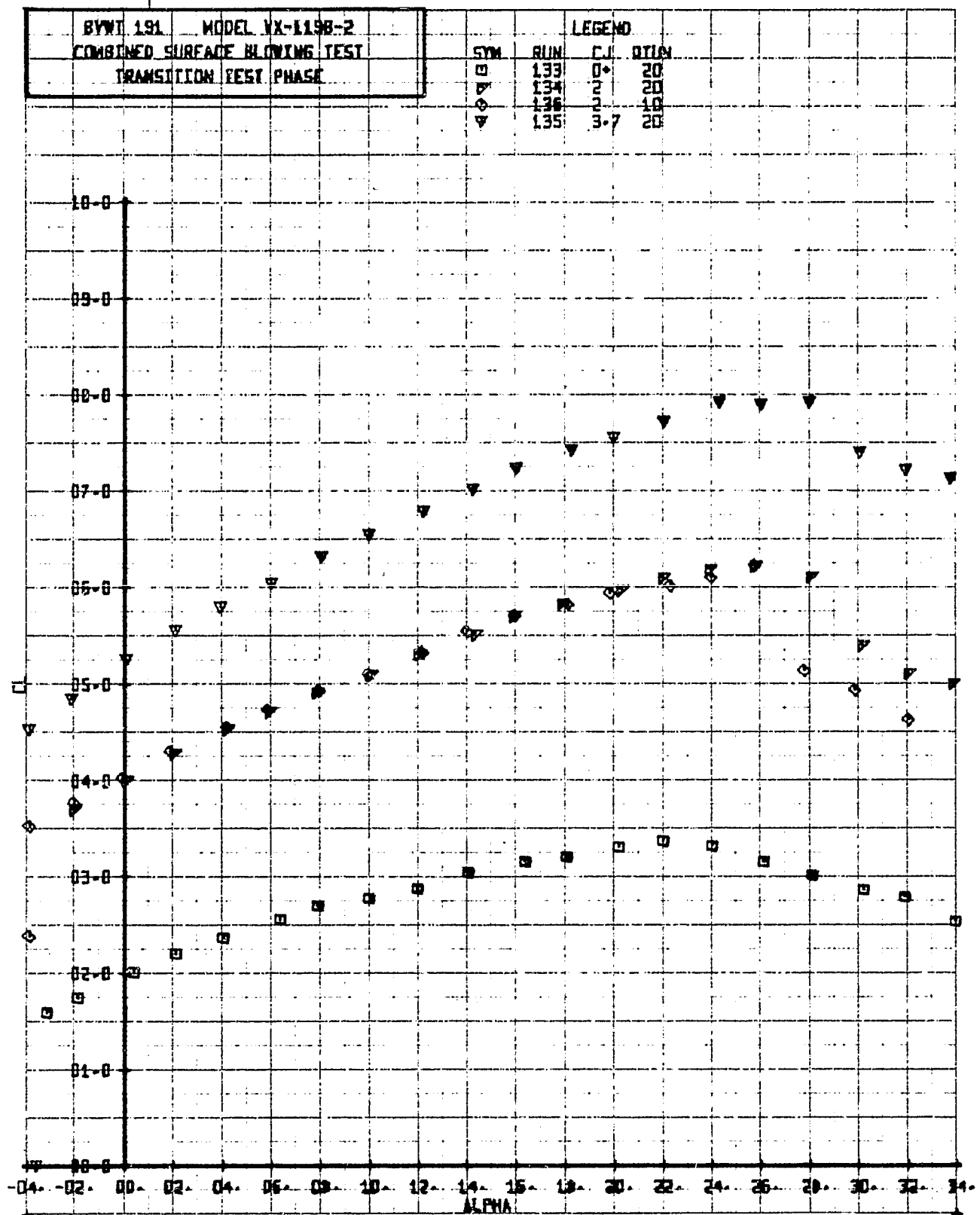


Figure 7.3-11. Extended Wing Performance with $\delta_f = 45^\circ$, Slat $S_1 S_3$
a. $C_L - \alpha$

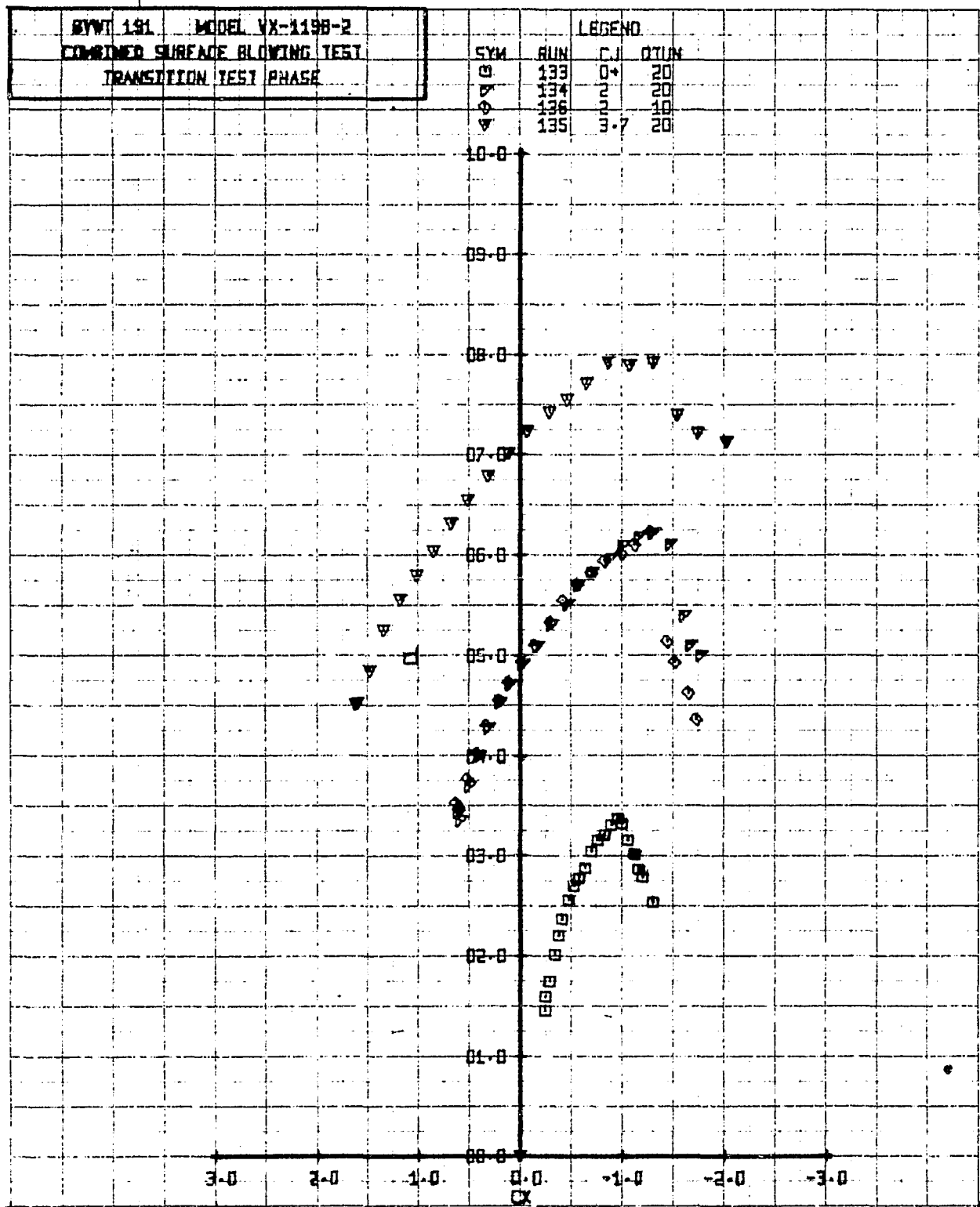


Figure 7.3-11. Extended-Wing Performance with $\delta_f = 45^\circ$, Slat $S_1 S_3$
 b. $C_L - C_X$

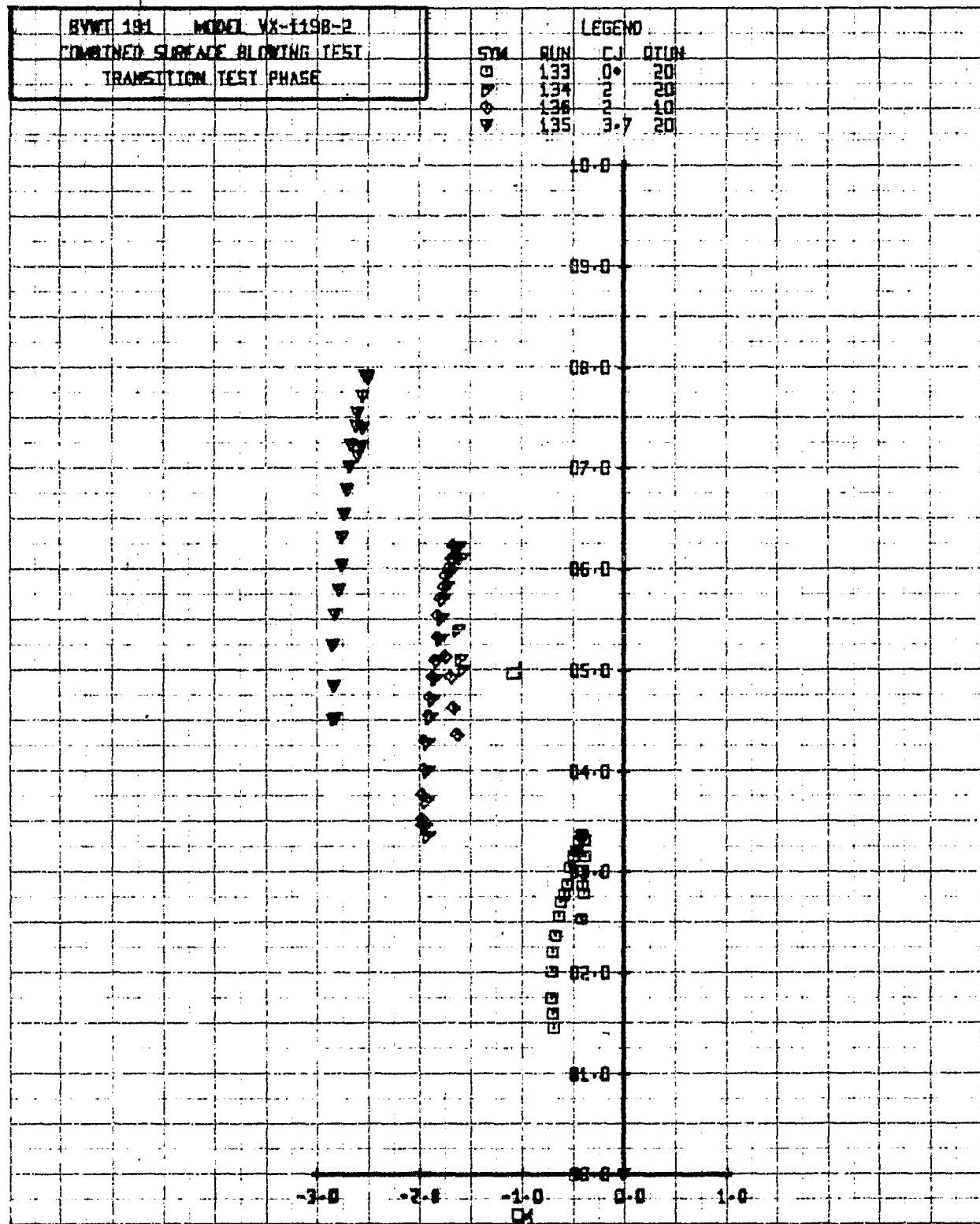


Figure 7.3-11. Extended-Wing Performance with $\delta_f = 45^\circ$, Slat $S_1 S_3$
c. $C_L - C_m$

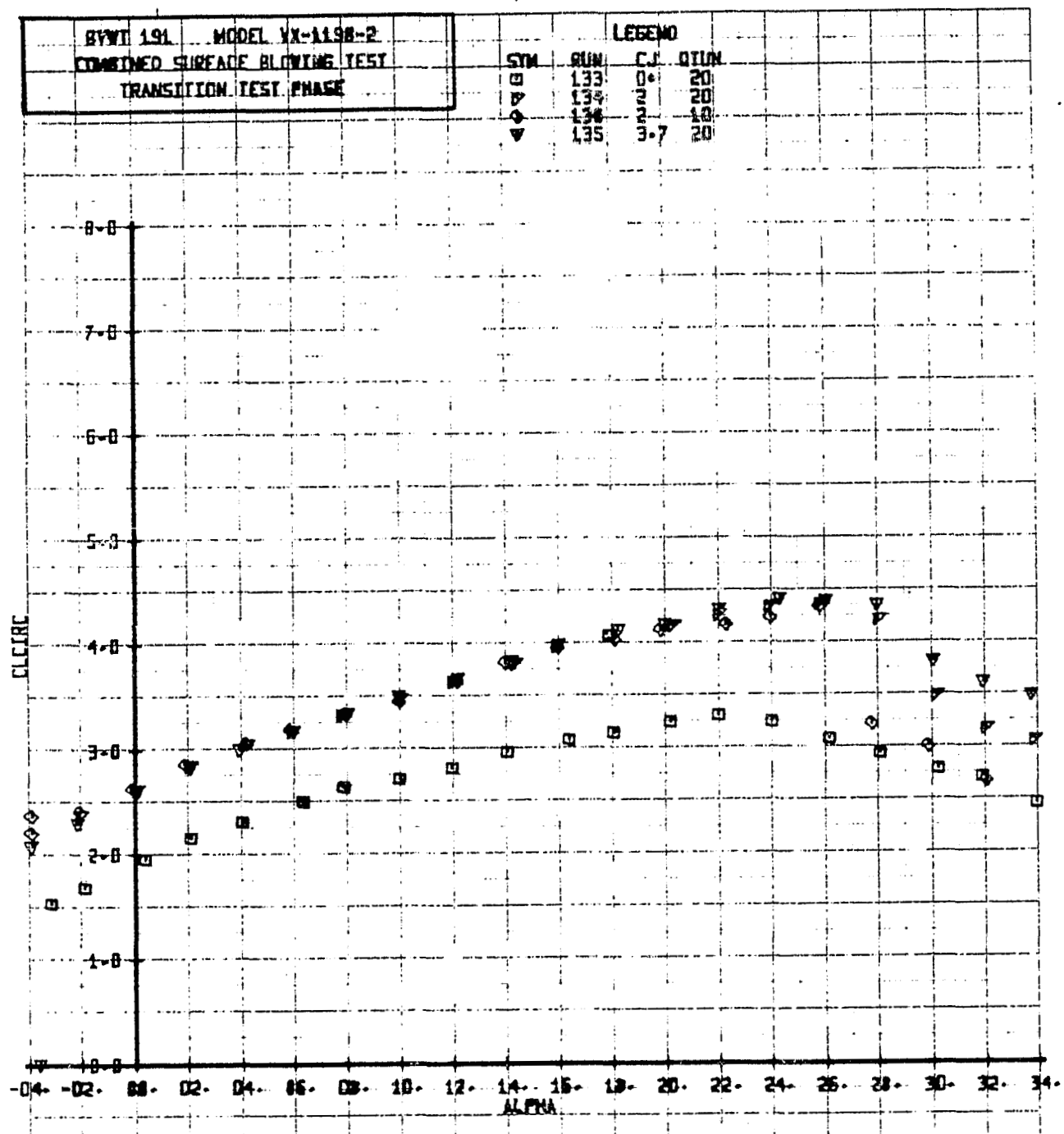


Figure 7.3-11. Extended-Wing Performance with $\delta_f = 45^\circ$, Slat $S_1 S_3$

d. $C_{L_{CIRC}} - \alpha$

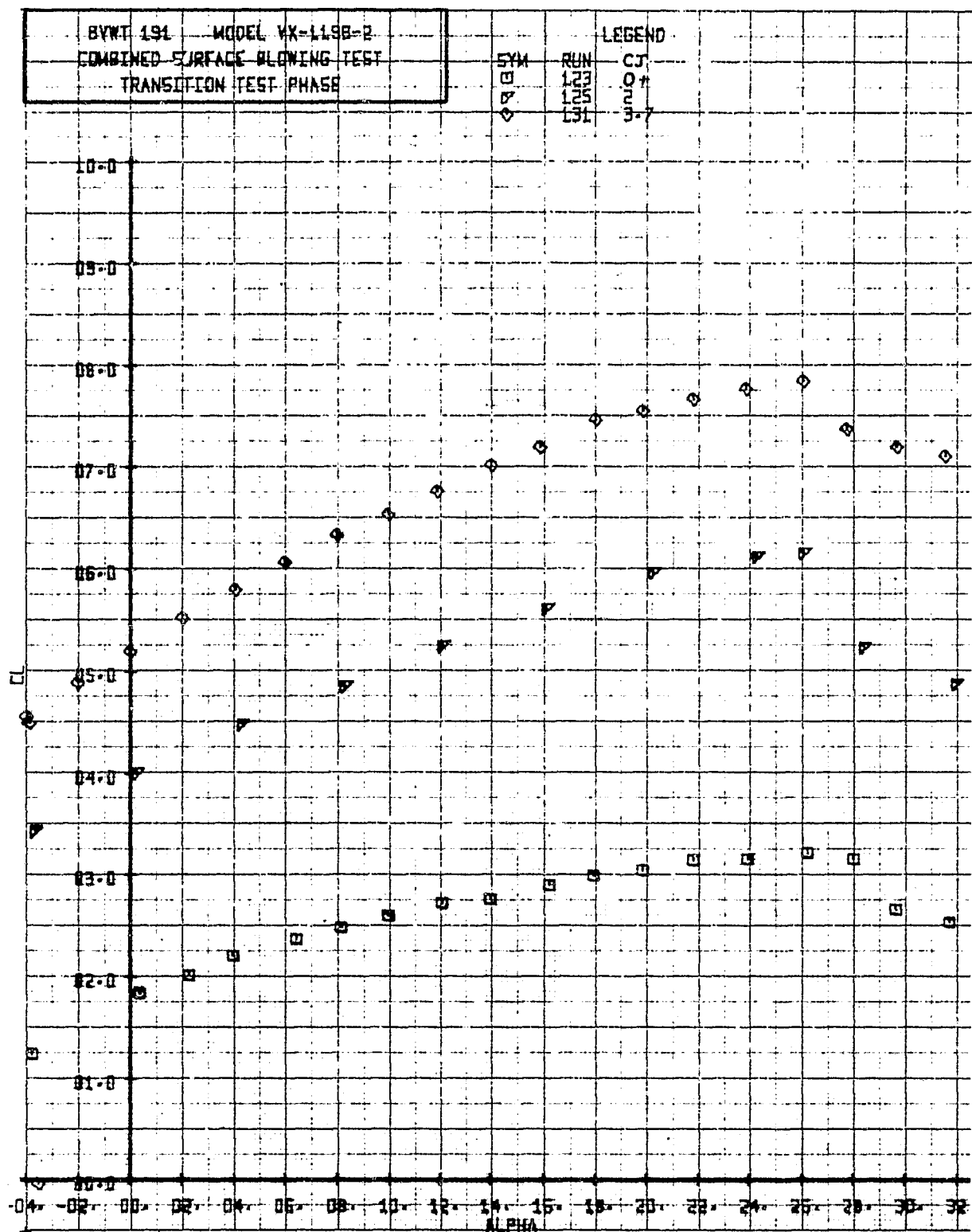


Figure 7.3-12. Extended-Wing Performance with $\delta_f = 45^\circ$, Slat S_1
 a. $C_L - \alpha$

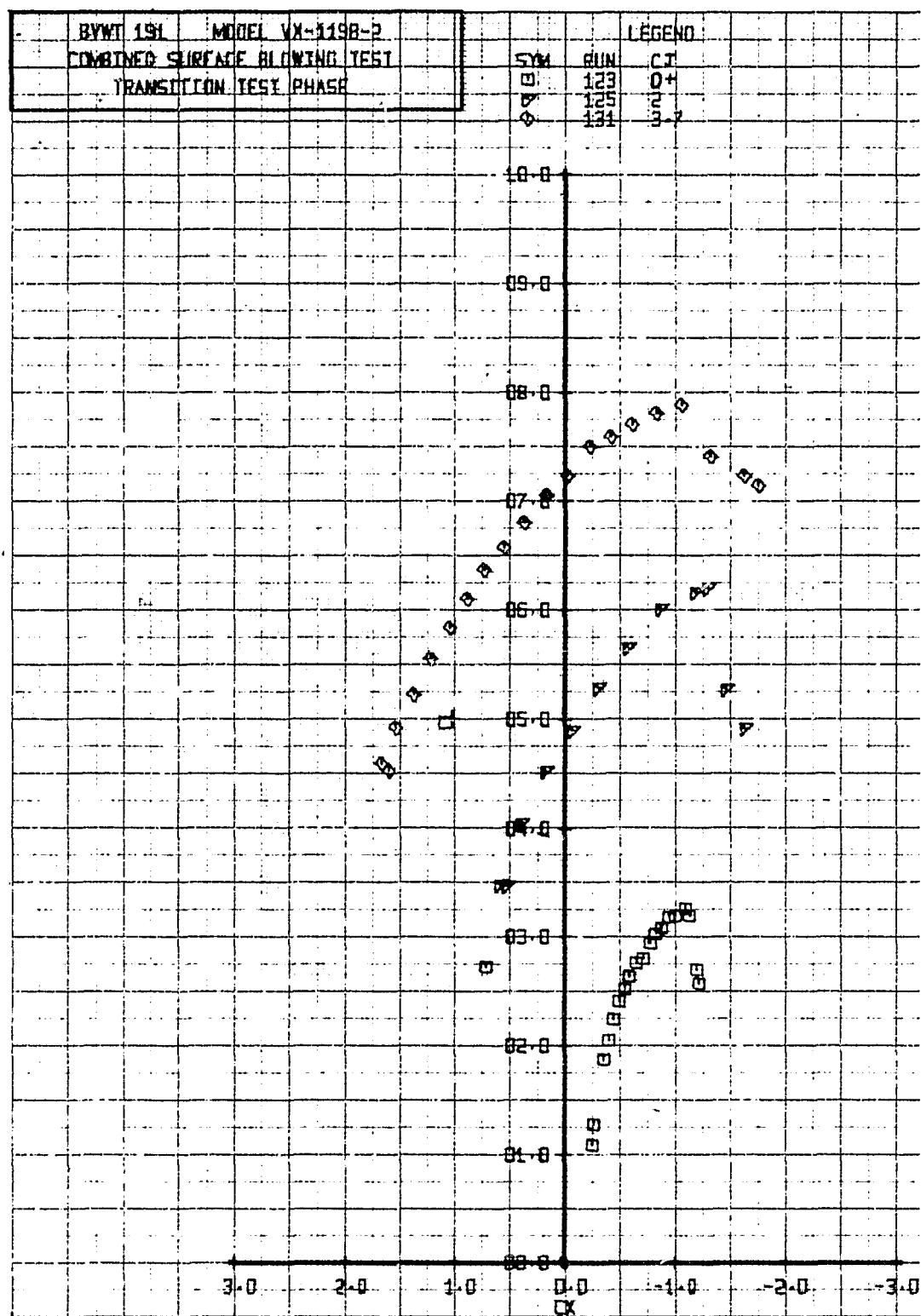


Figure 7.3-12. Extended-Wing Performance with $\delta_f = 45^\circ$, Slat S_1
b. $C_L - C_X$

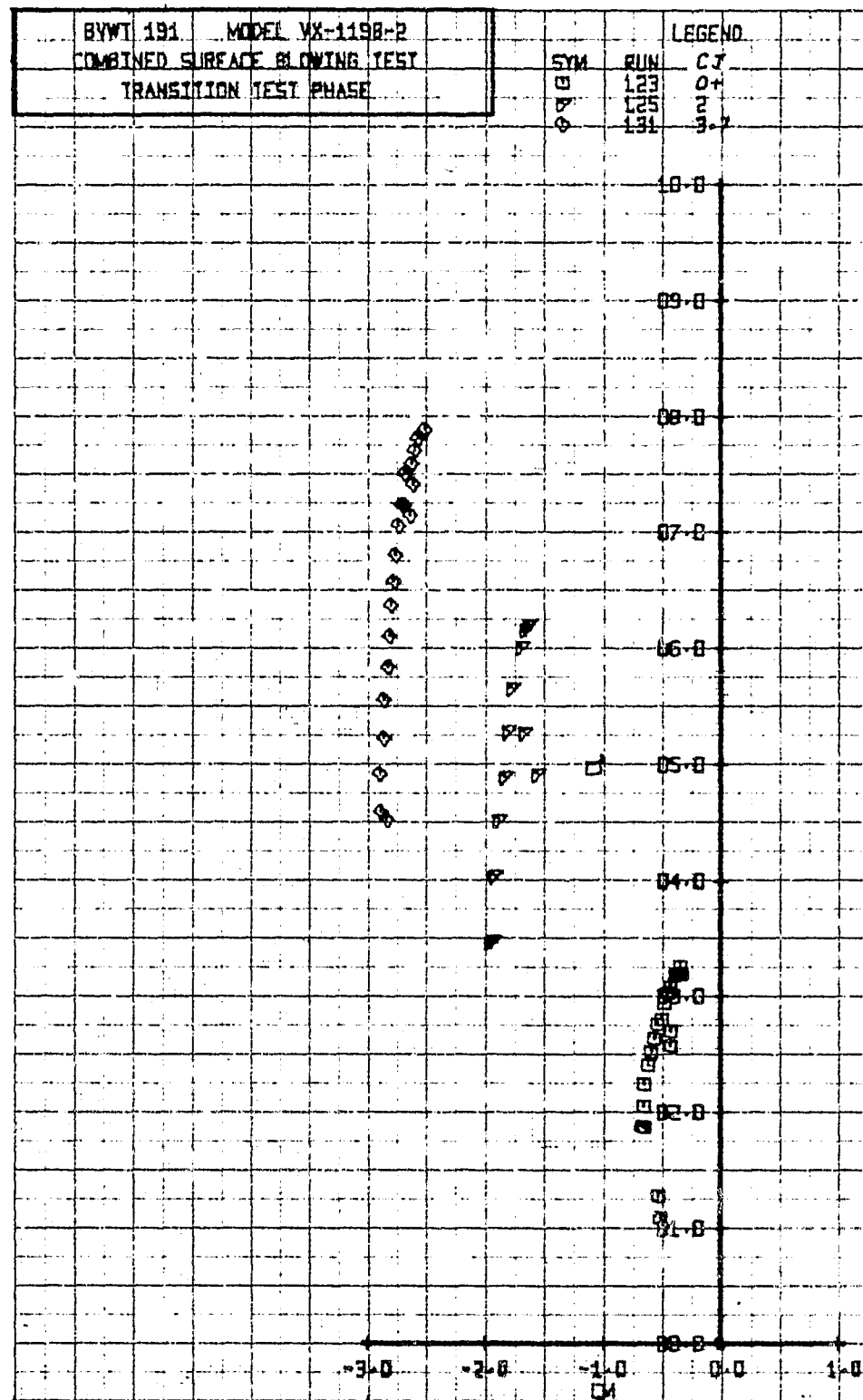


Figure 7.3-12. Extended-Wing Performance with $\delta_f = 45^\circ$, Slat S_1
c. $C_L - C_m$

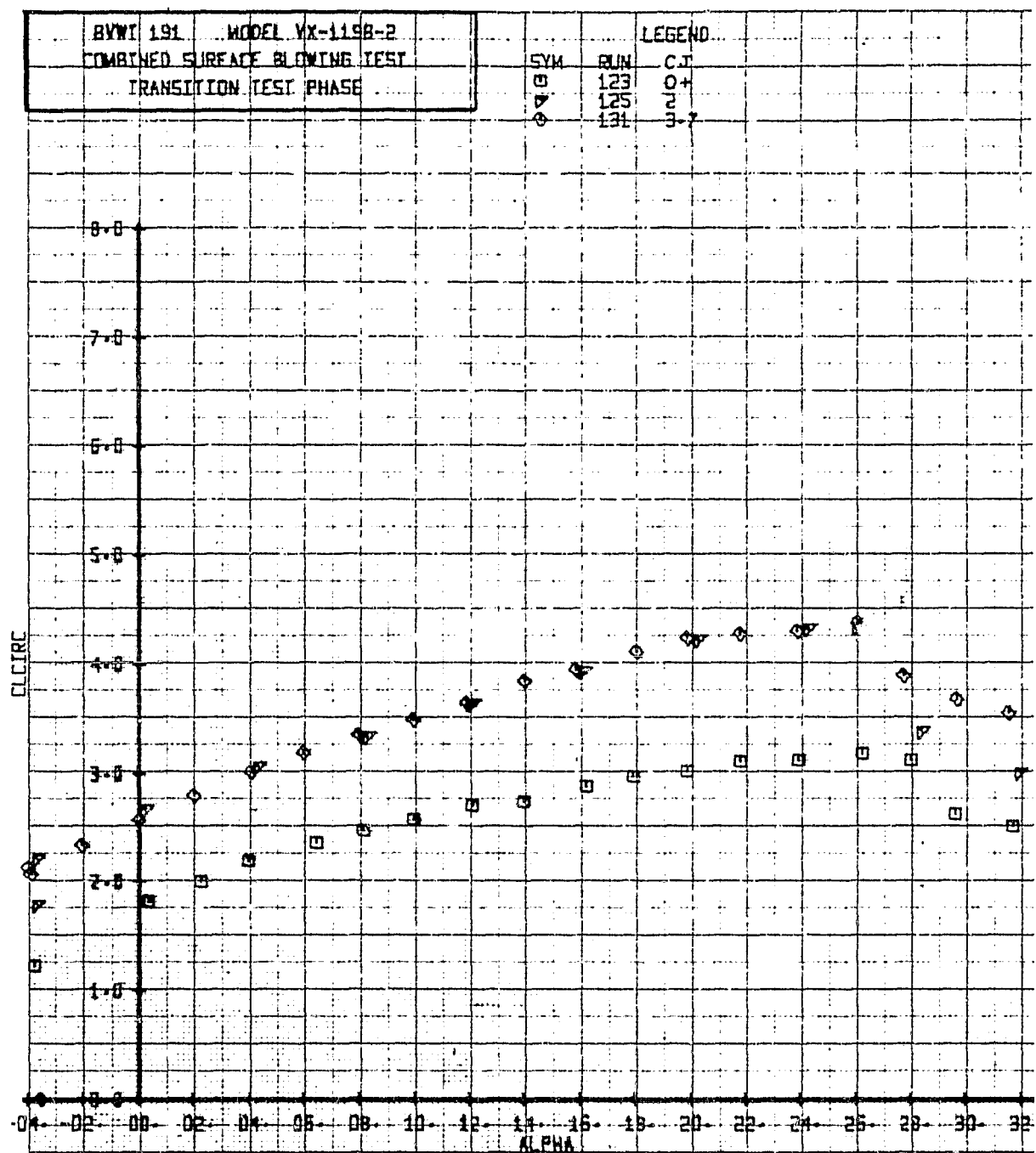


Figure 7.3-12. Extended-Wing Performance with $\delta_f = 45^\circ$, Slat S_1
 d. $C_{LCIRC} - \alpha$

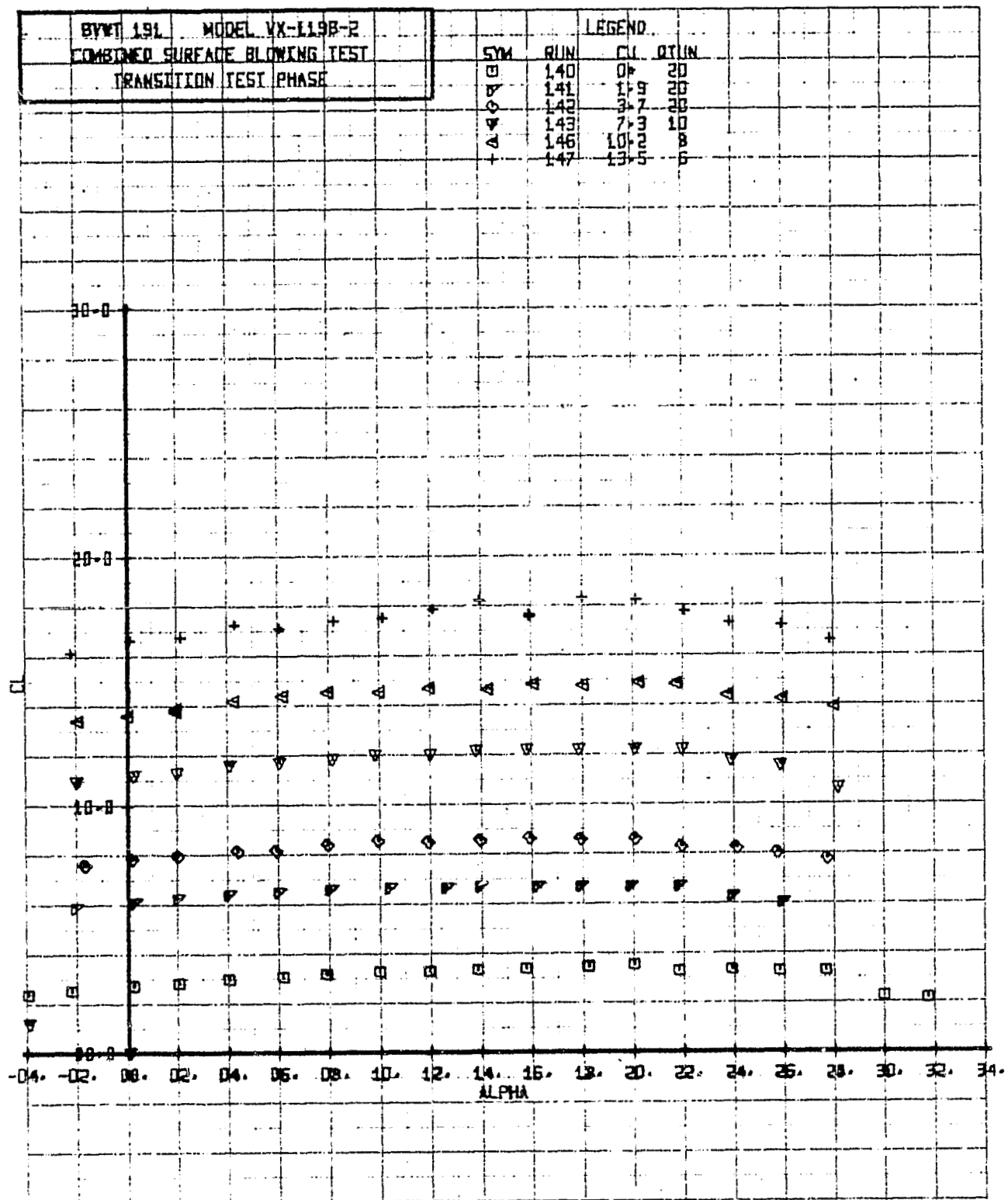


Figure 7.3-13. Extended-Wing Performance with $\delta_f = 75^\circ$
a. $C_L - \alpha$

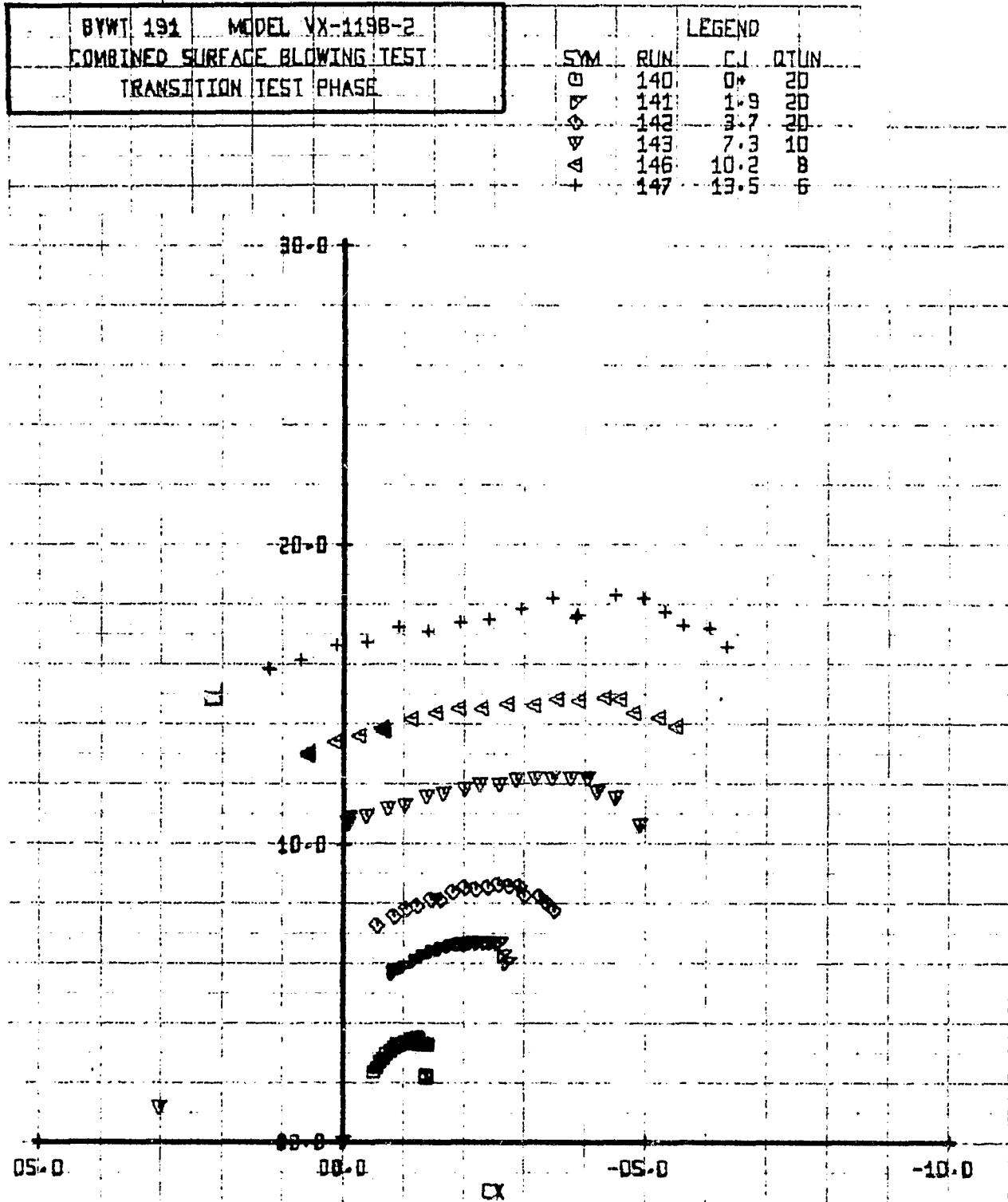


Figure 7.3-13. Extended-Wing Performance with $\delta_f = 75^\circ$
 b. $C_L - C_X$

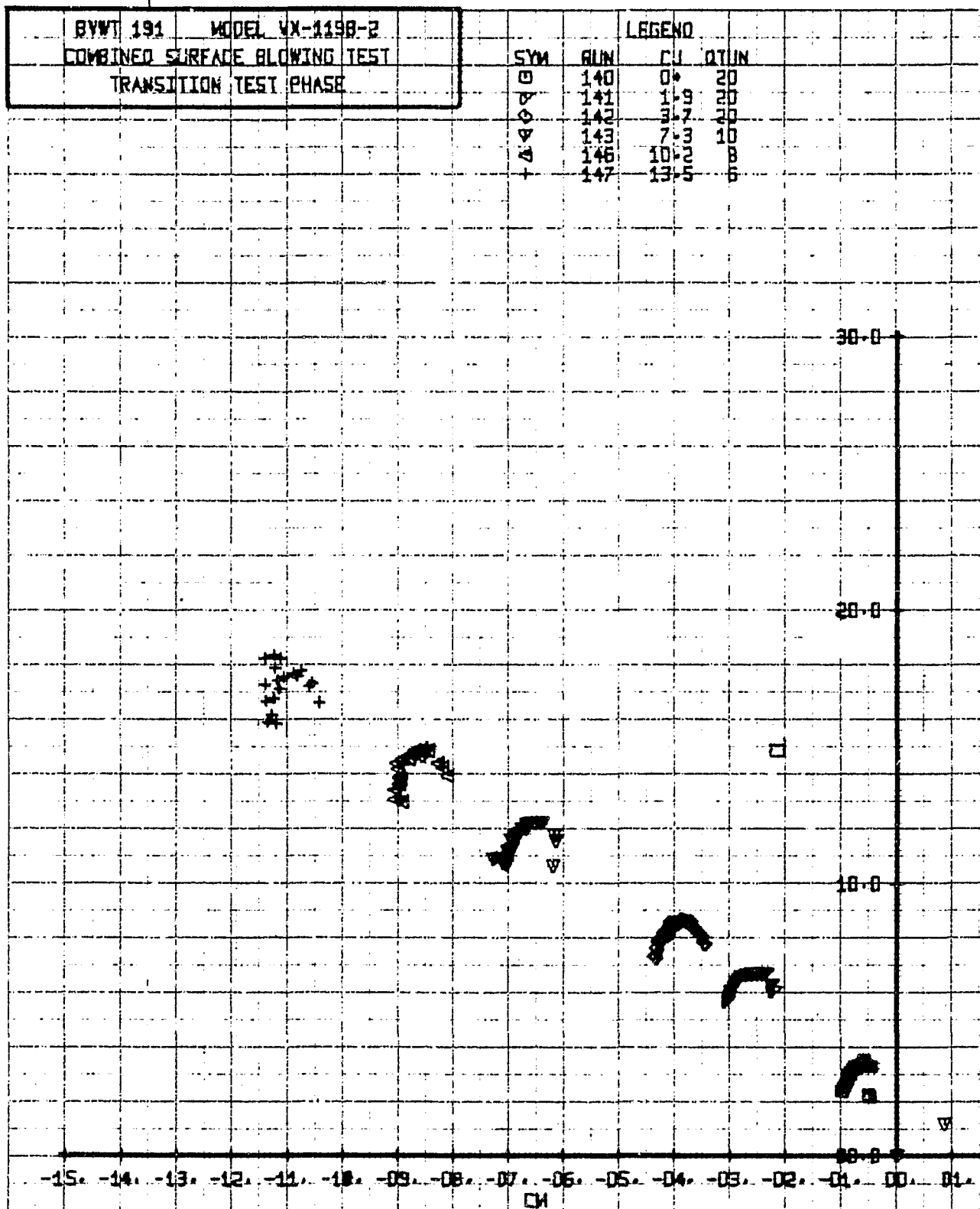


Figure 7.3-13. Extended-Wing Performance with $\delta_f = 75^\circ$
c. $C_L - C_m$

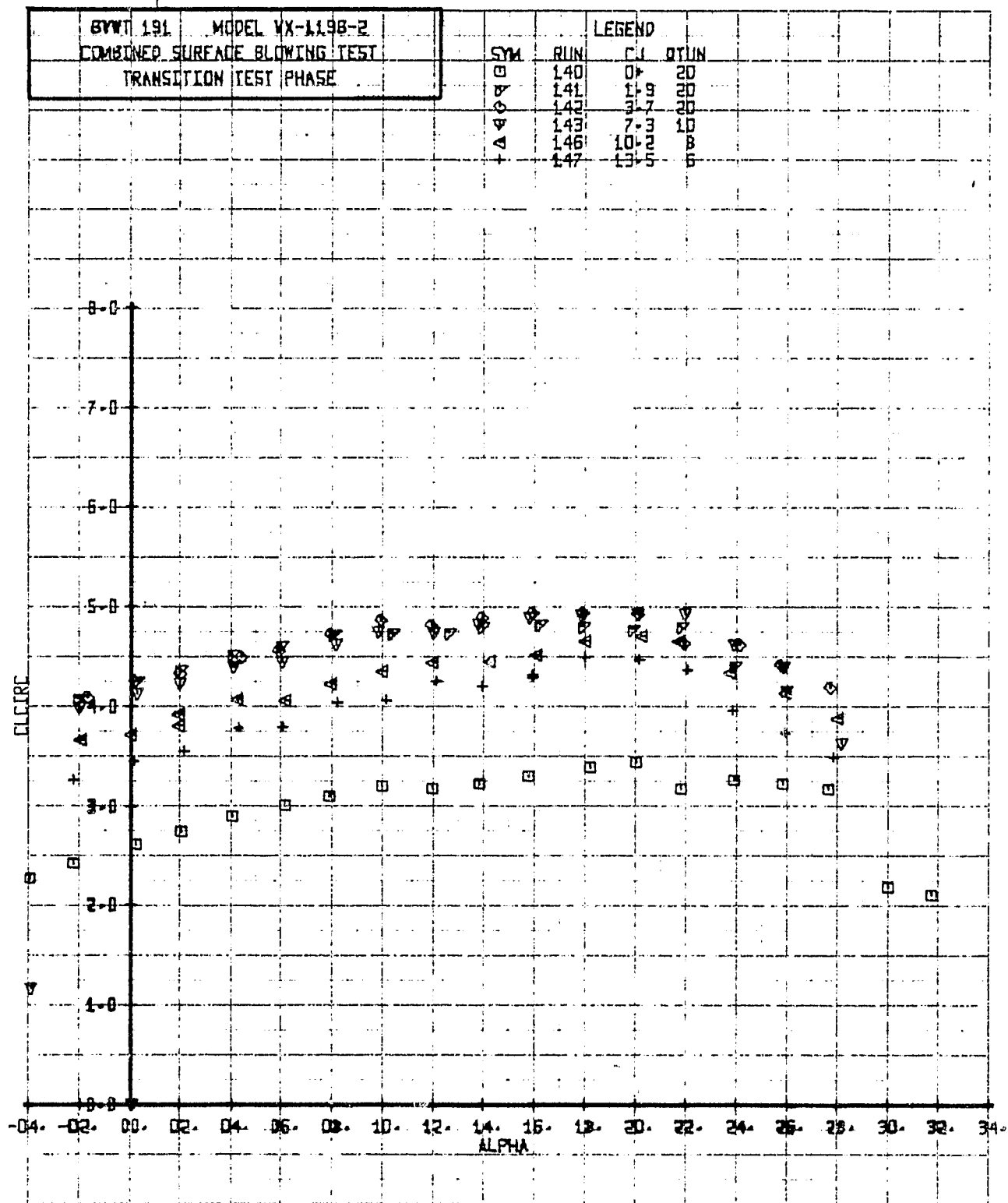


Figure 7.3-13. Extended-Wing Performance with $\delta_f = 75^\circ$
d. $C_{LCIRC} - \alpha$

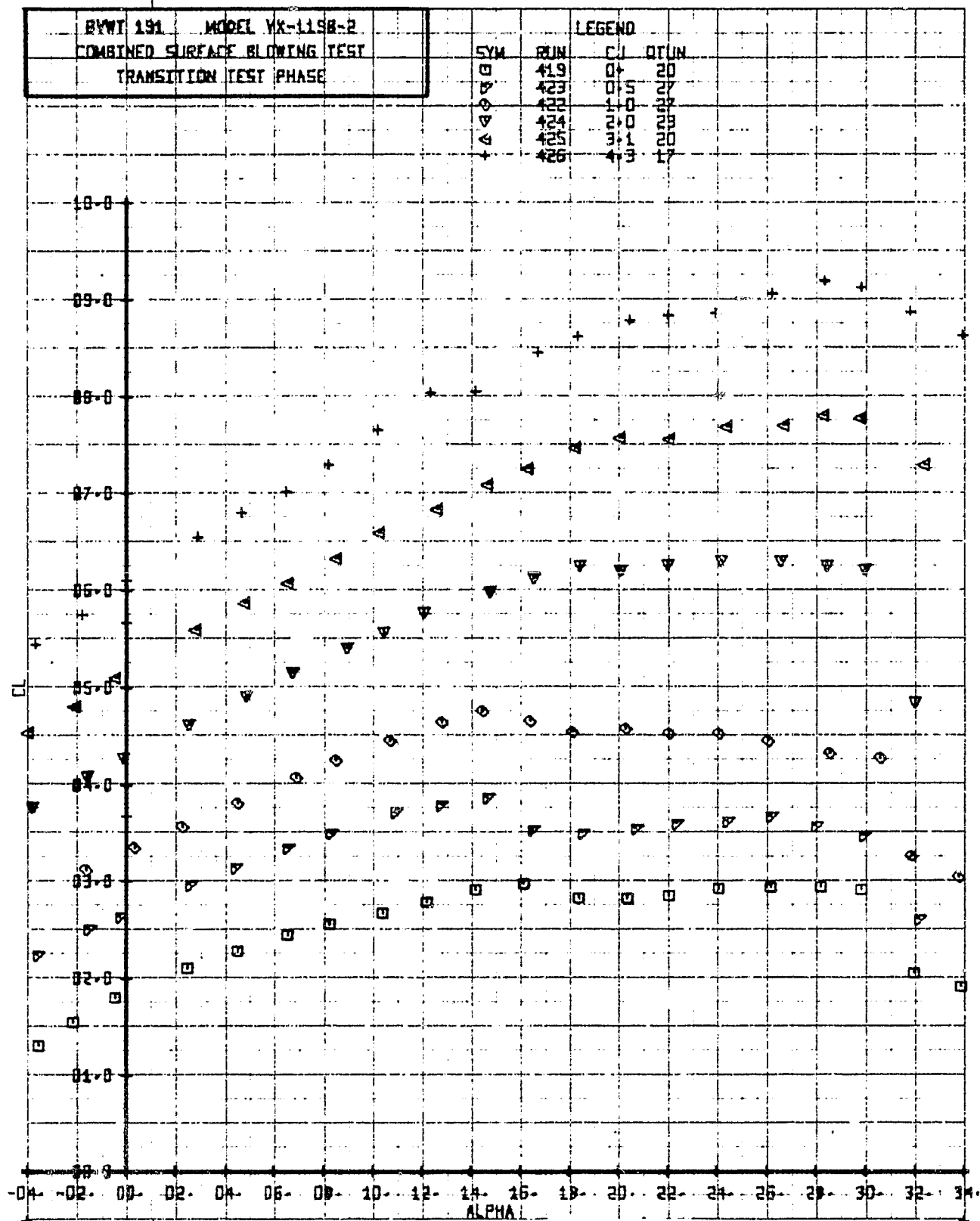


Figure 7.3-14. Retracted-Wing Performance with $\delta_f = 45^\circ$
a. $C_L - \alpha$

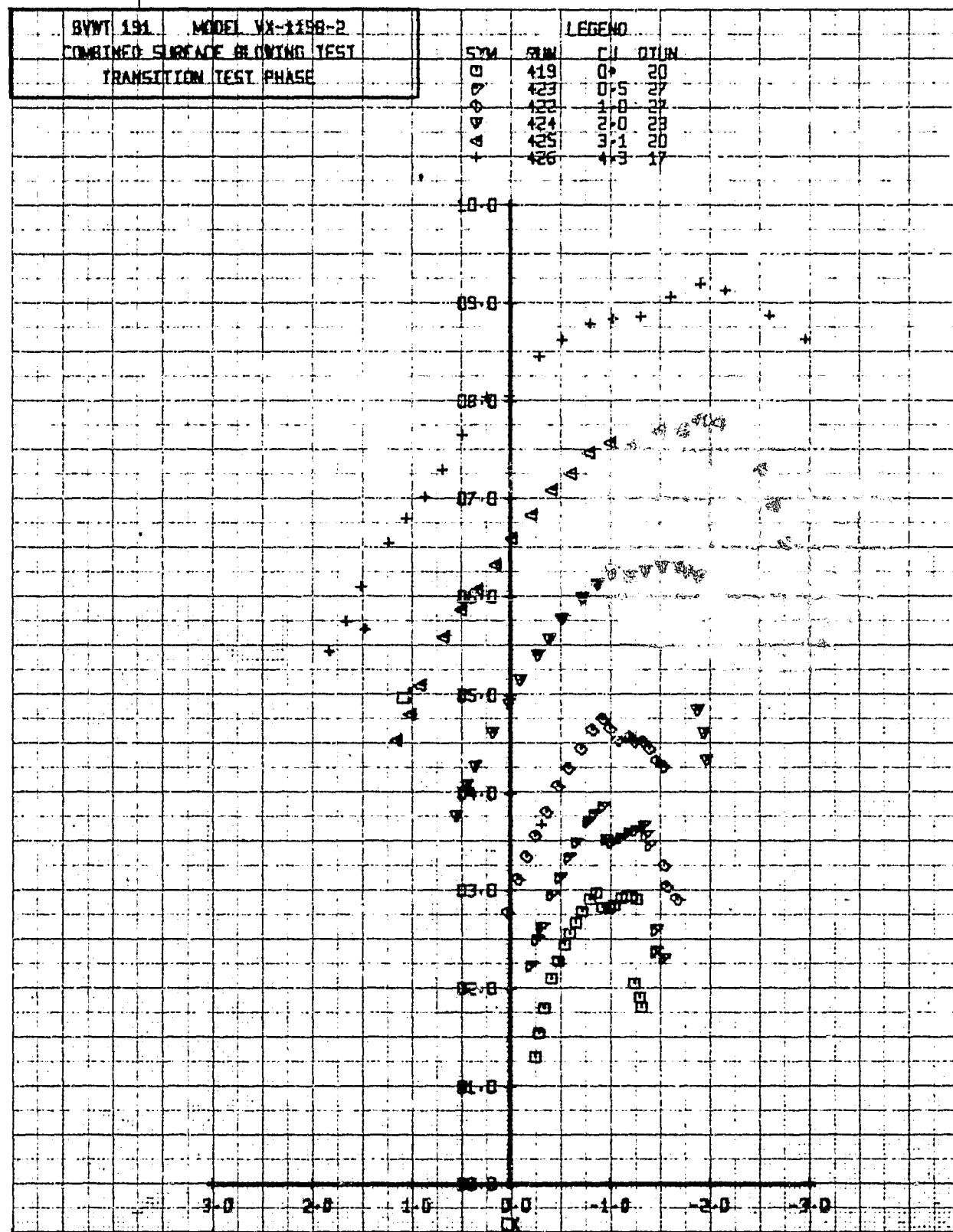


Figure 7.3-14. Retracted-Wing Performance with $\delta_f = 45^\circ$
b. $C_L - C_X$

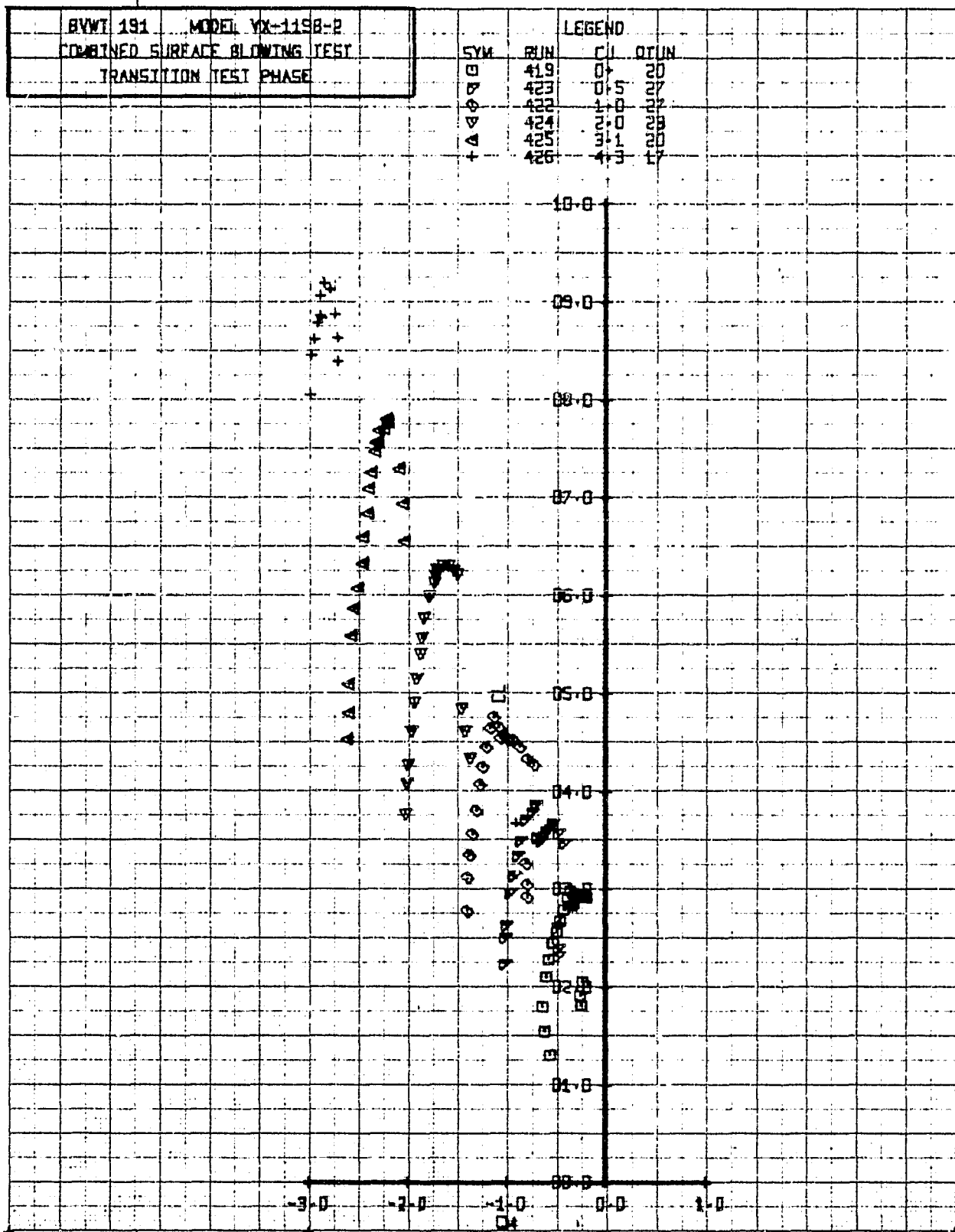


Figure 7.3-14. Retracted-Wing Performance with $\delta_f = 45^\circ$
c. $C_L - C_m$

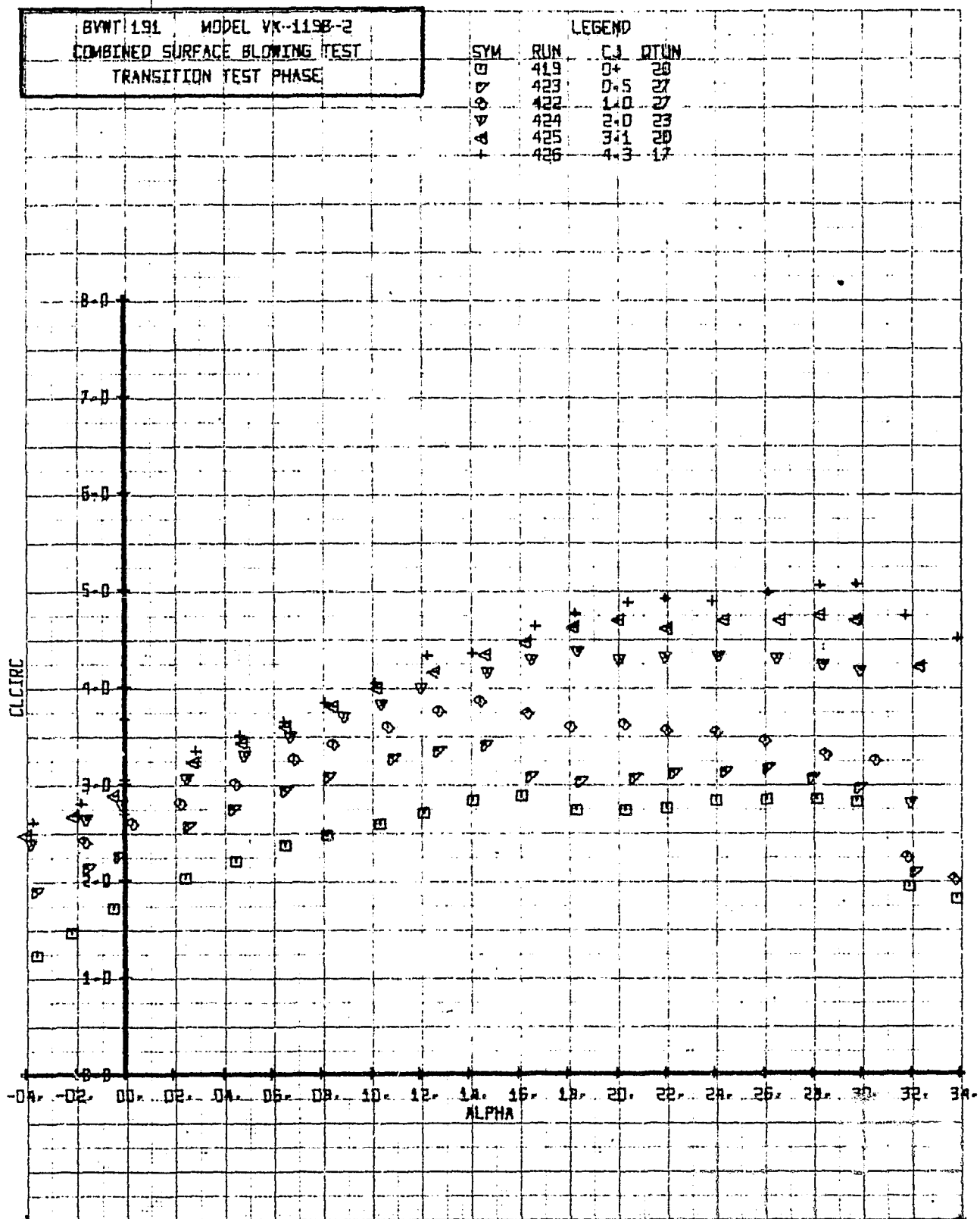


Figure 7.3-14. Retracted-Wing Performance with $\delta_f = 45^\circ$

d. $C_{L_{CIRC}} - \alpha$

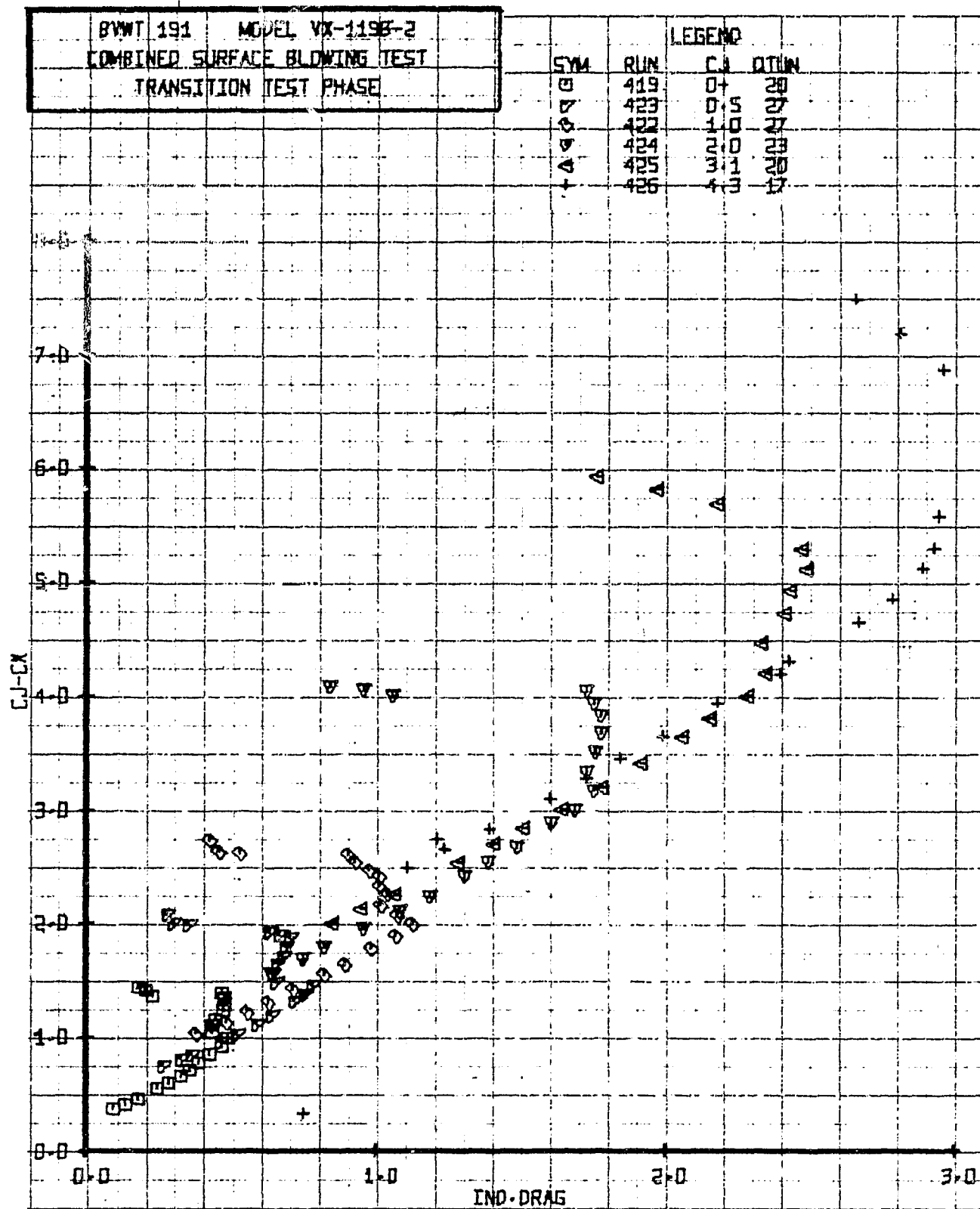


Figure 7.3-14. Retracted-Wing Performance with $\delta_f = 45^\circ$
e. Induced Drag

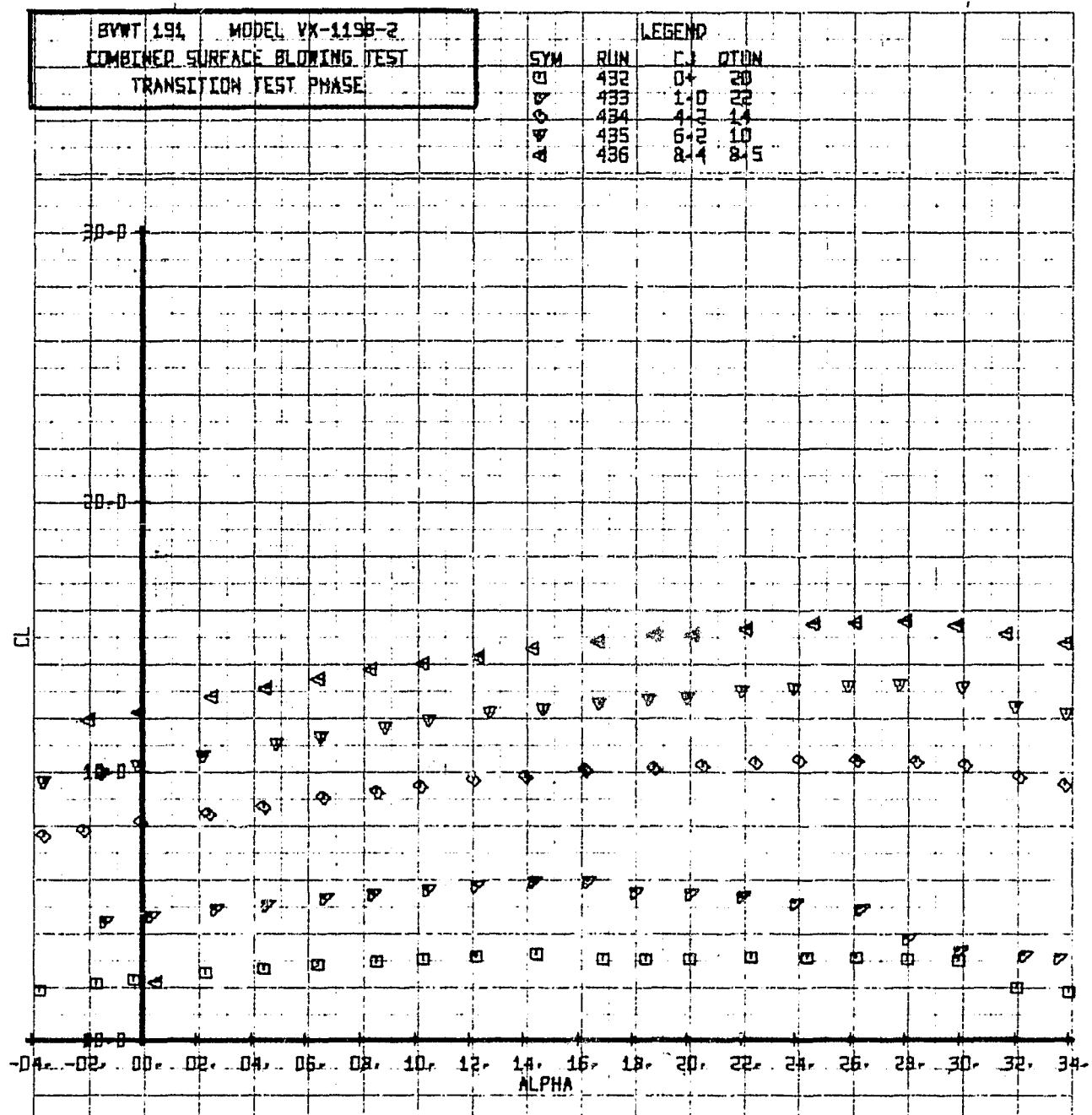


Figure 7.3-15. Retracted-Wing Performance with $\delta_f = 60^\circ$

a. $C_L - \alpha$

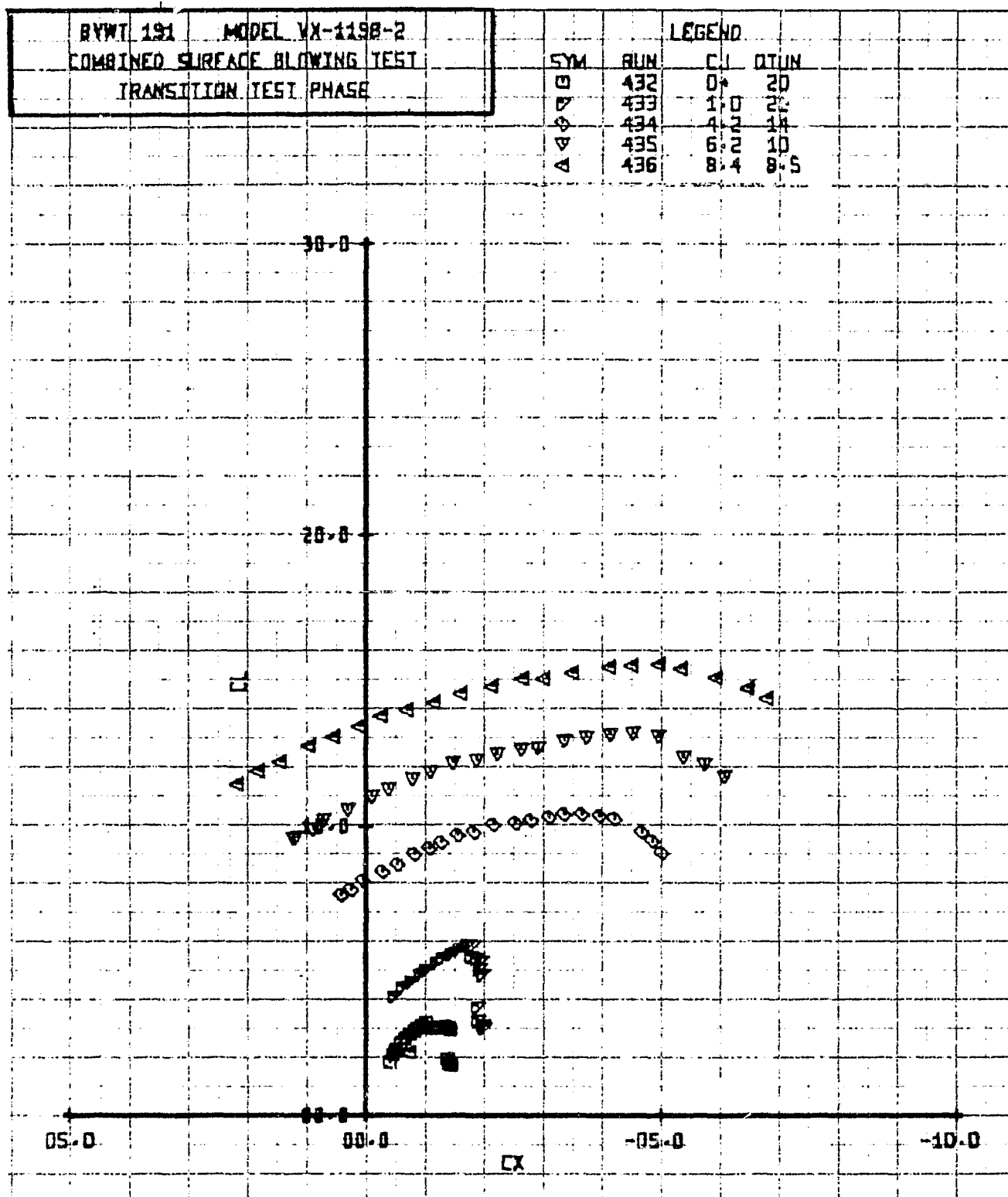


Figure 7.3-15. Retracted-Wing Performance with $\delta_f = 60^\circ$

b. $C_L - C_X$

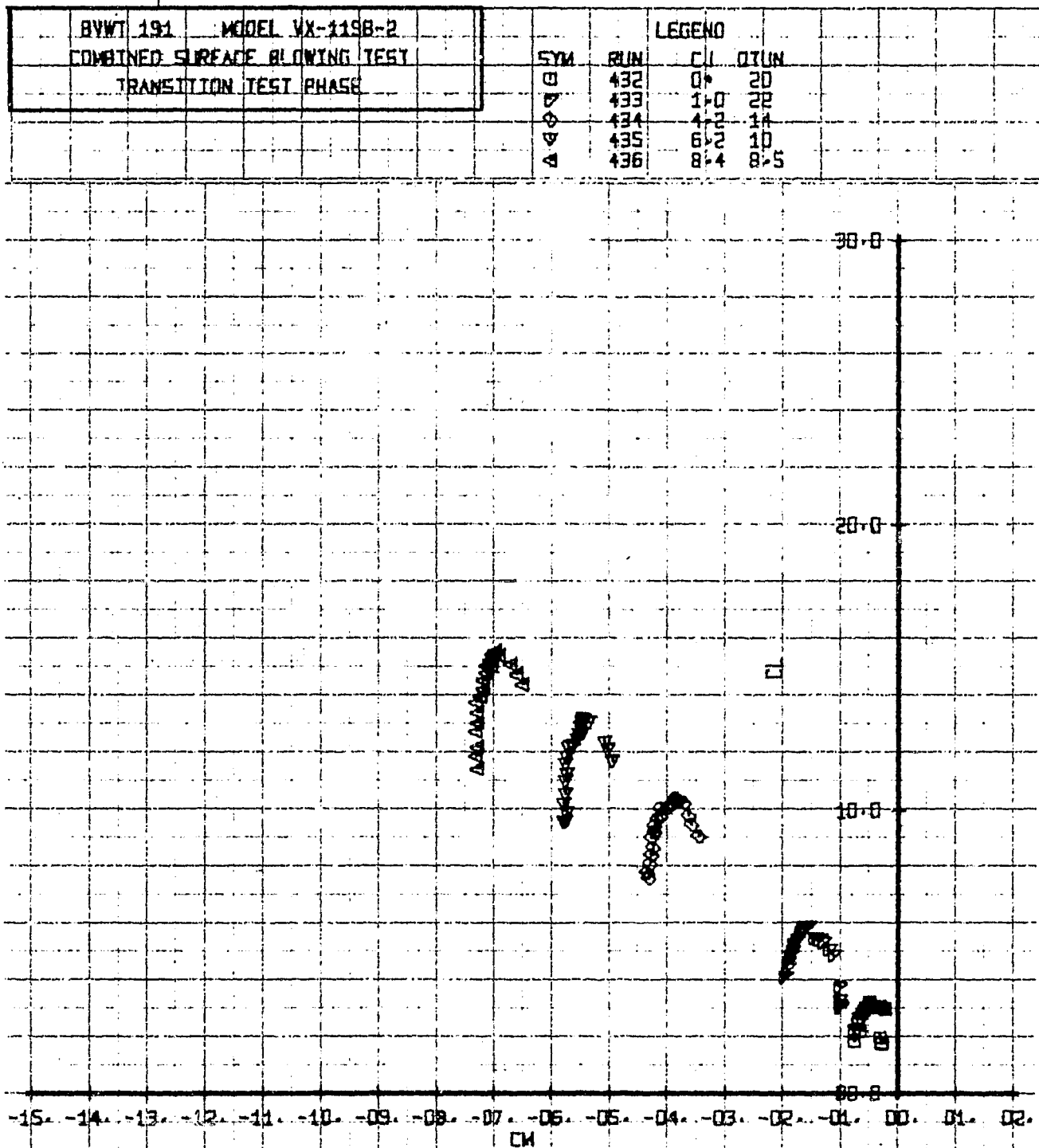


Figure 7.3-15. Retracted-Wing Performance with $\delta_f = 60^\circ$

c. $C_L - C_m$

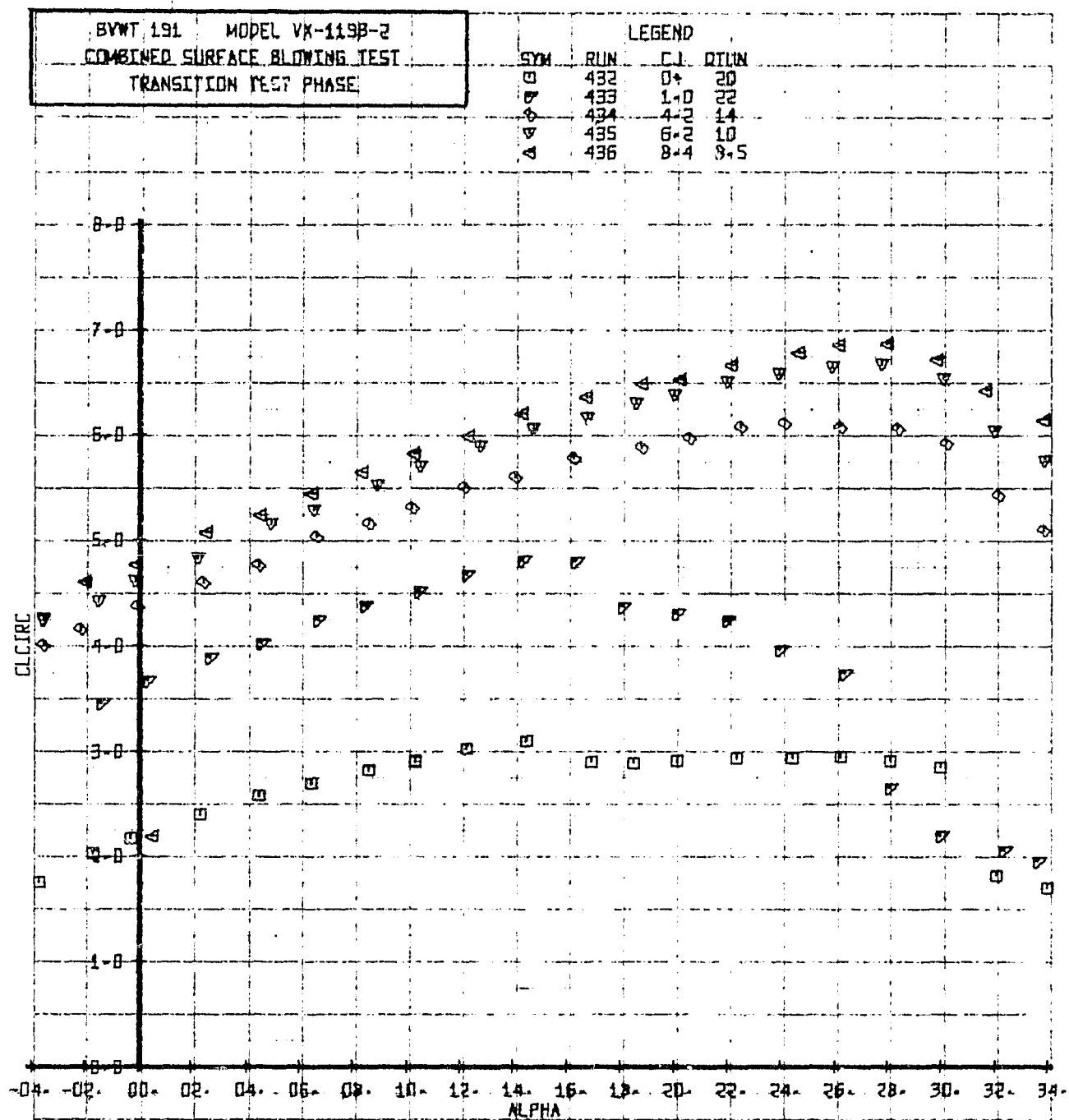


Figure 7.3-15. Retracted-Wing Performance with $\delta_f = 60^\circ$

d. $C_{LCIRC} - \alpha$

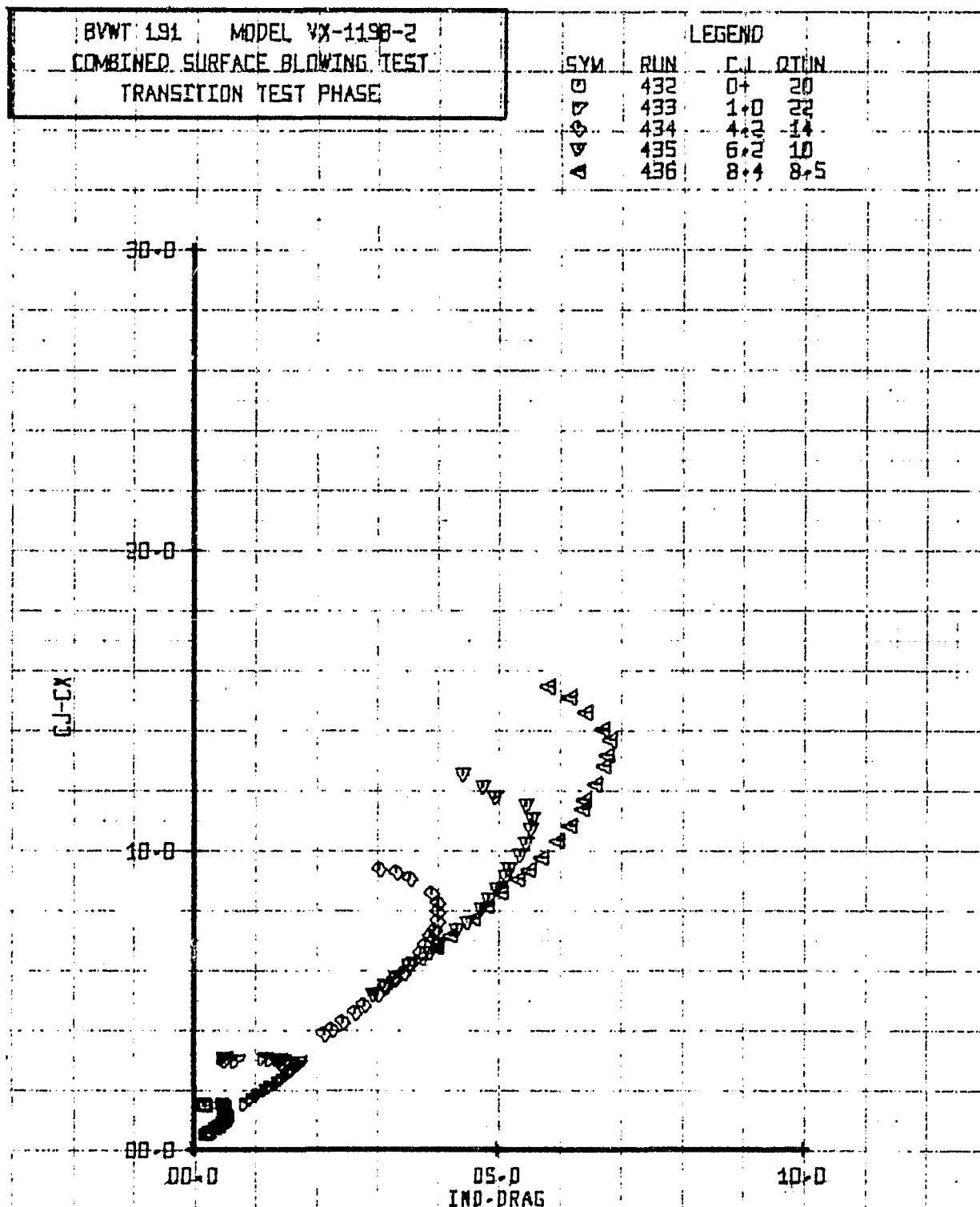


Figure 7.3-15. Retracted-Wing Performance with $\delta_f = 60^\circ$
e. Induced Drag

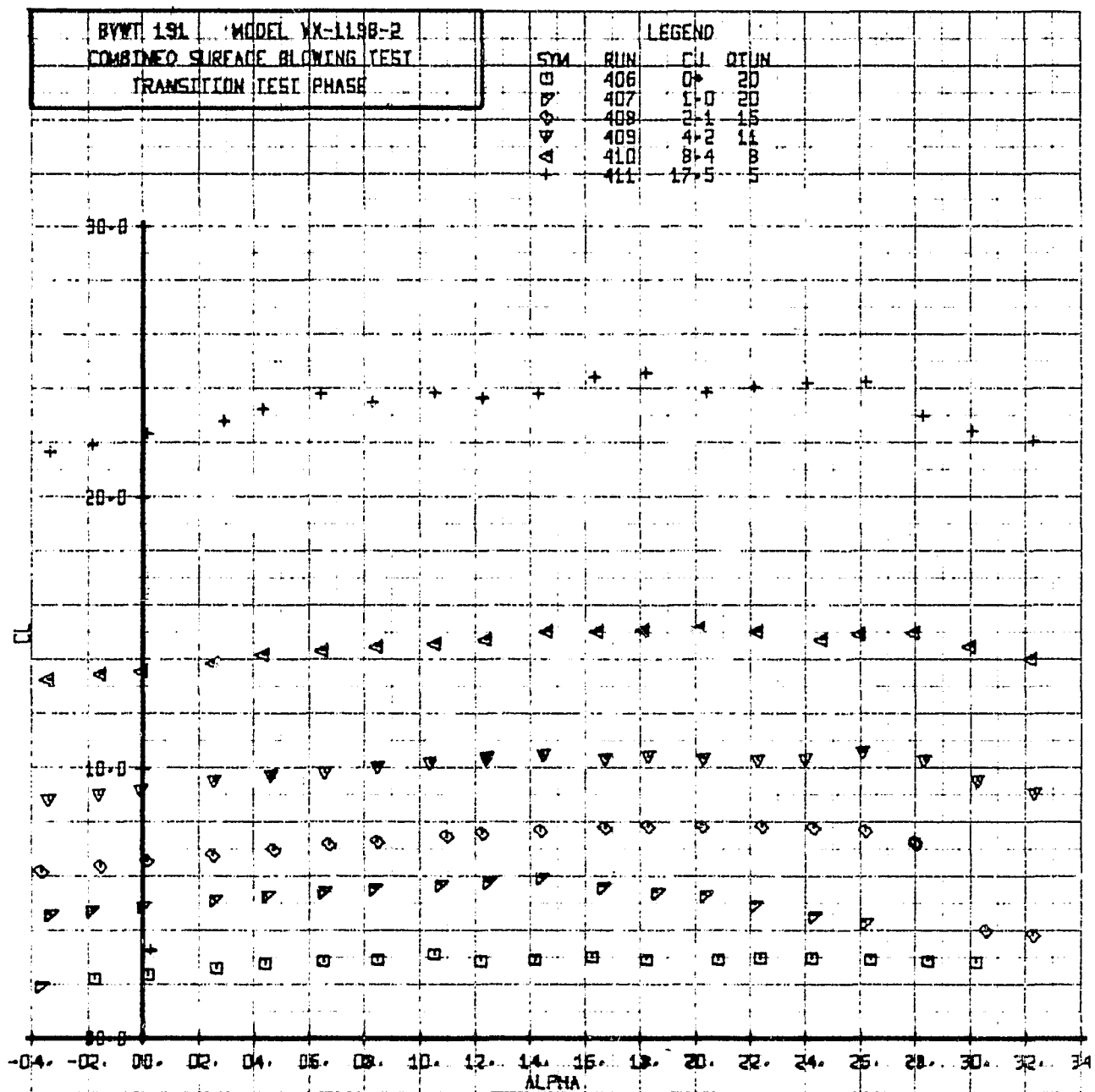


Figure 7.3-16. Retracted-Wing Performance with $\delta_f = 75^\circ$
a. $C_L - \alpha$

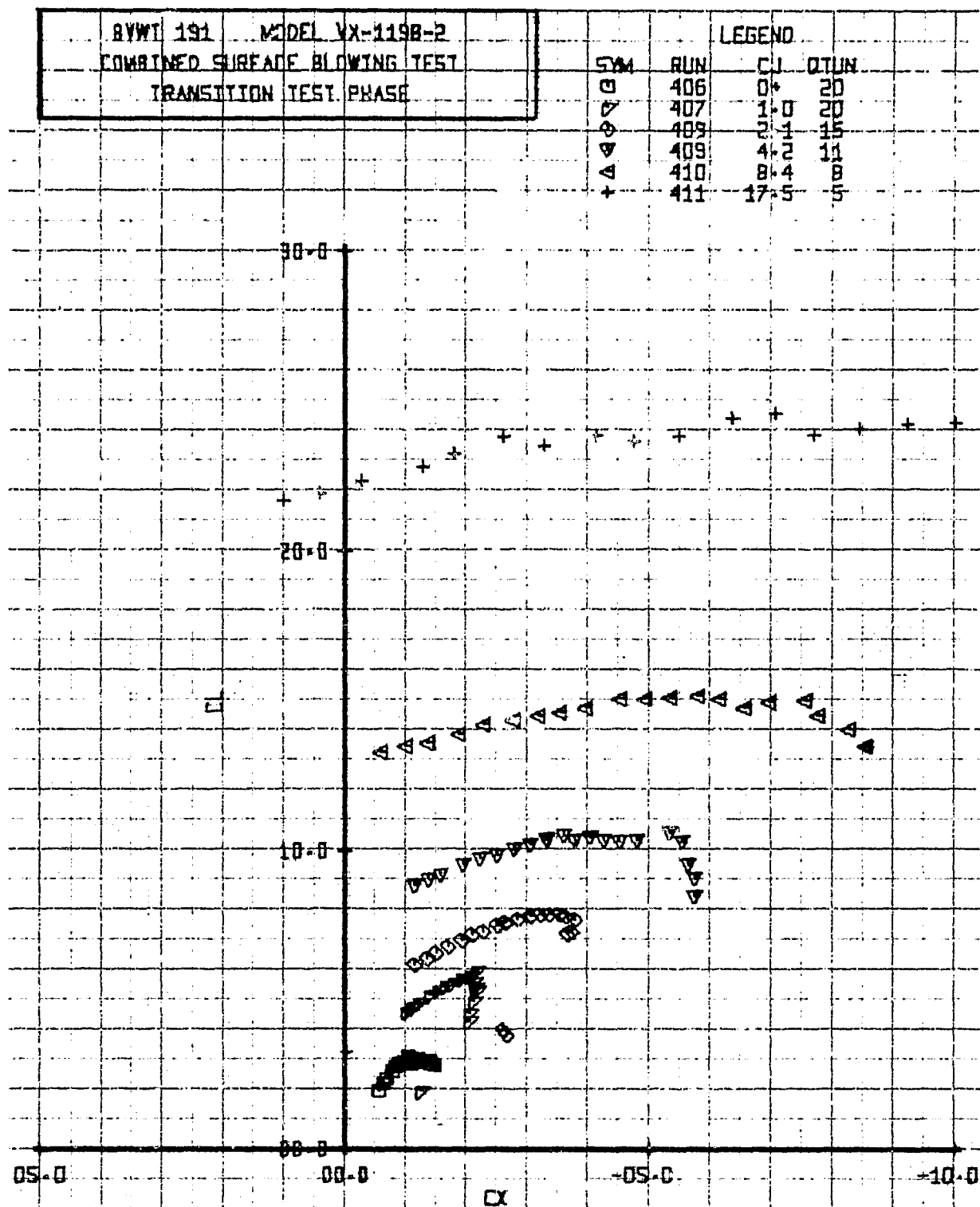


Figure 7.3-16. Retracted-Wing Performance with $\delta_f = 75^\circ$
 b. $C_L - C_X$

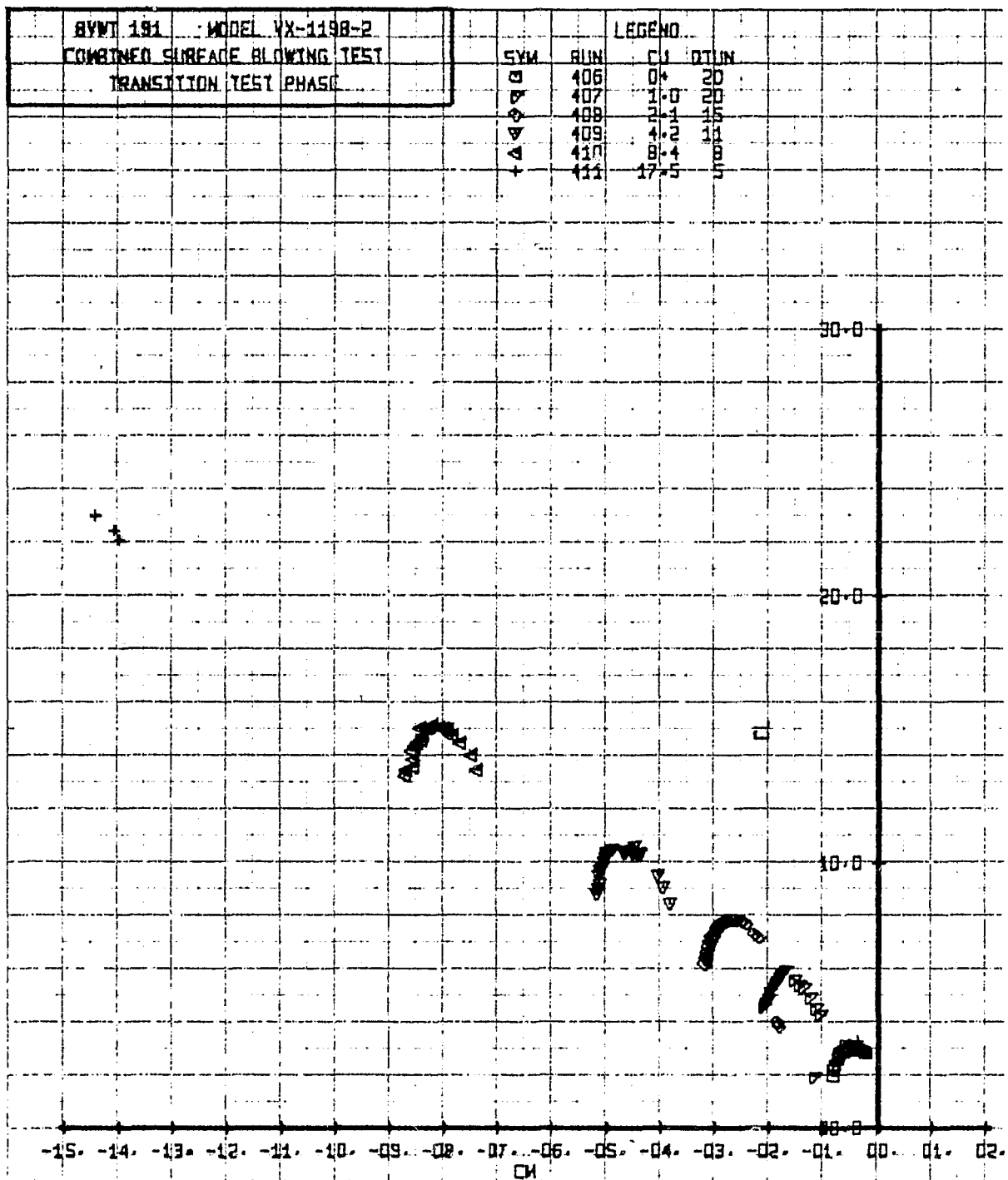


Figure 7.3-16. Retracted-Wing Performance with $\delta_f = 75^\circ$
 c. $C_L - C_m$

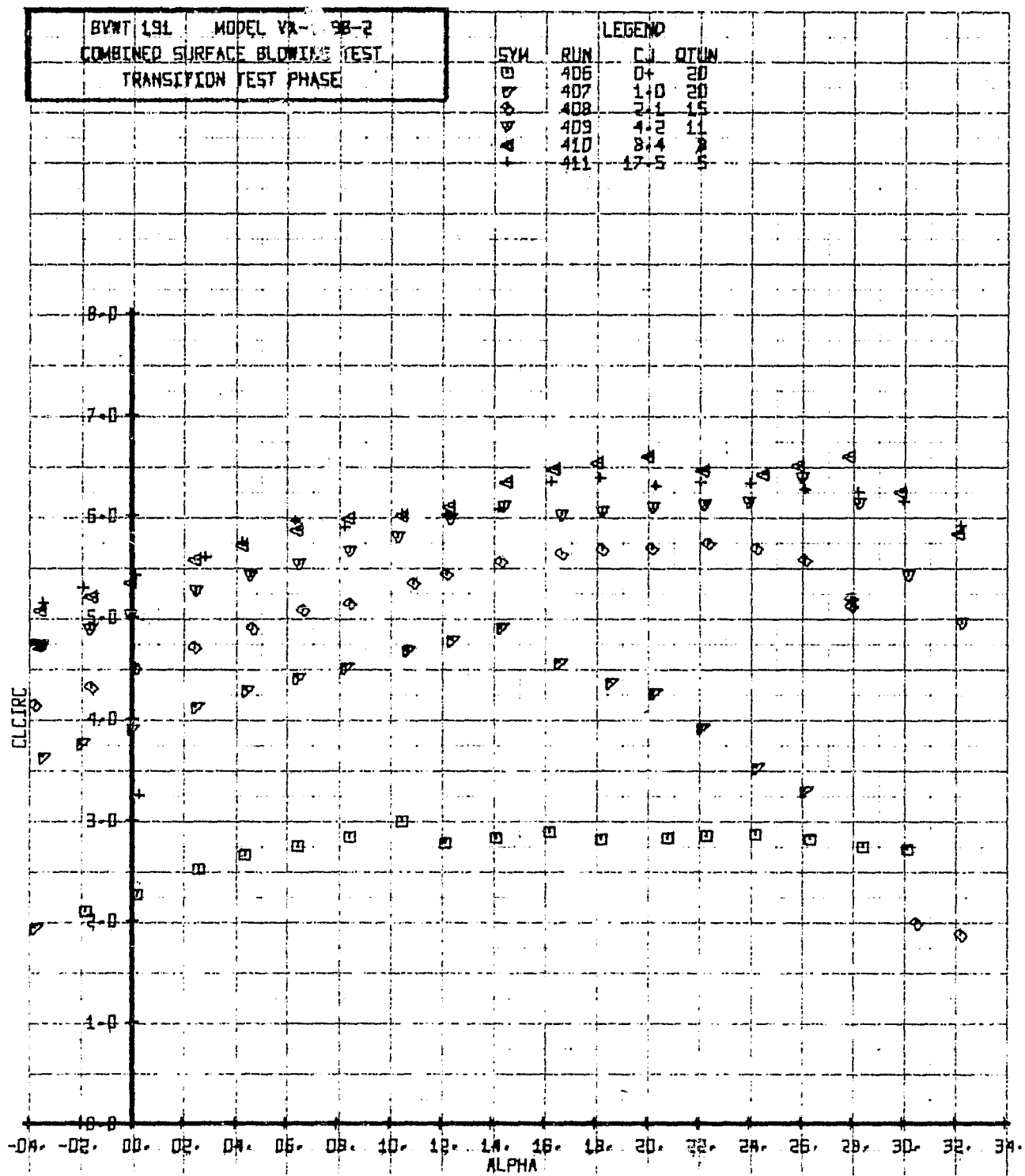


Figure 7.3-16. Retracted-Wing Performance with $\delta_f = 75^\circ$
d. $C_{LCIRC} - \alpha$

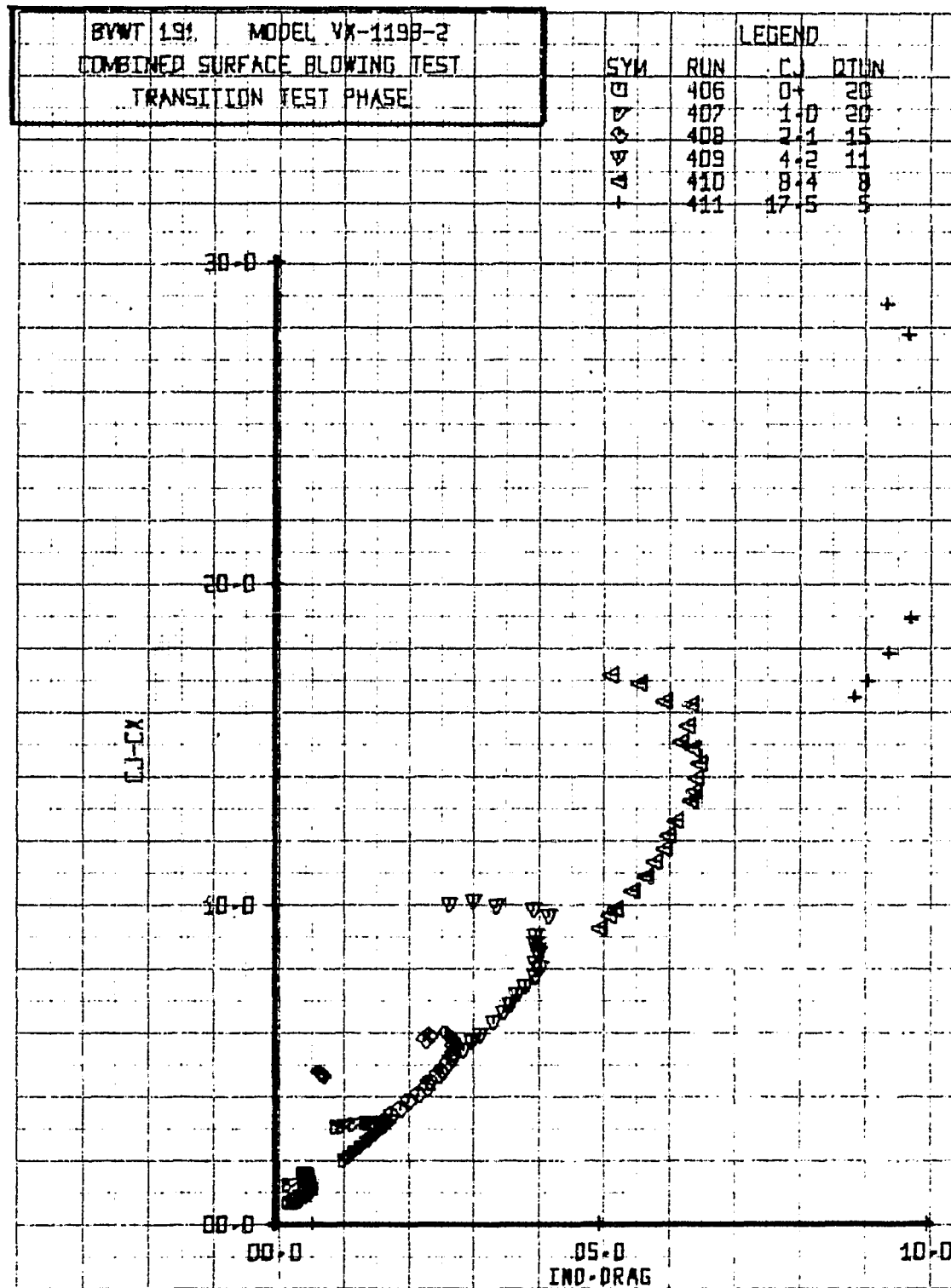


Figure 7.3-16. Retracted-Wing Performance with $\delta_f = 75^\circ$
e. Induced Drag

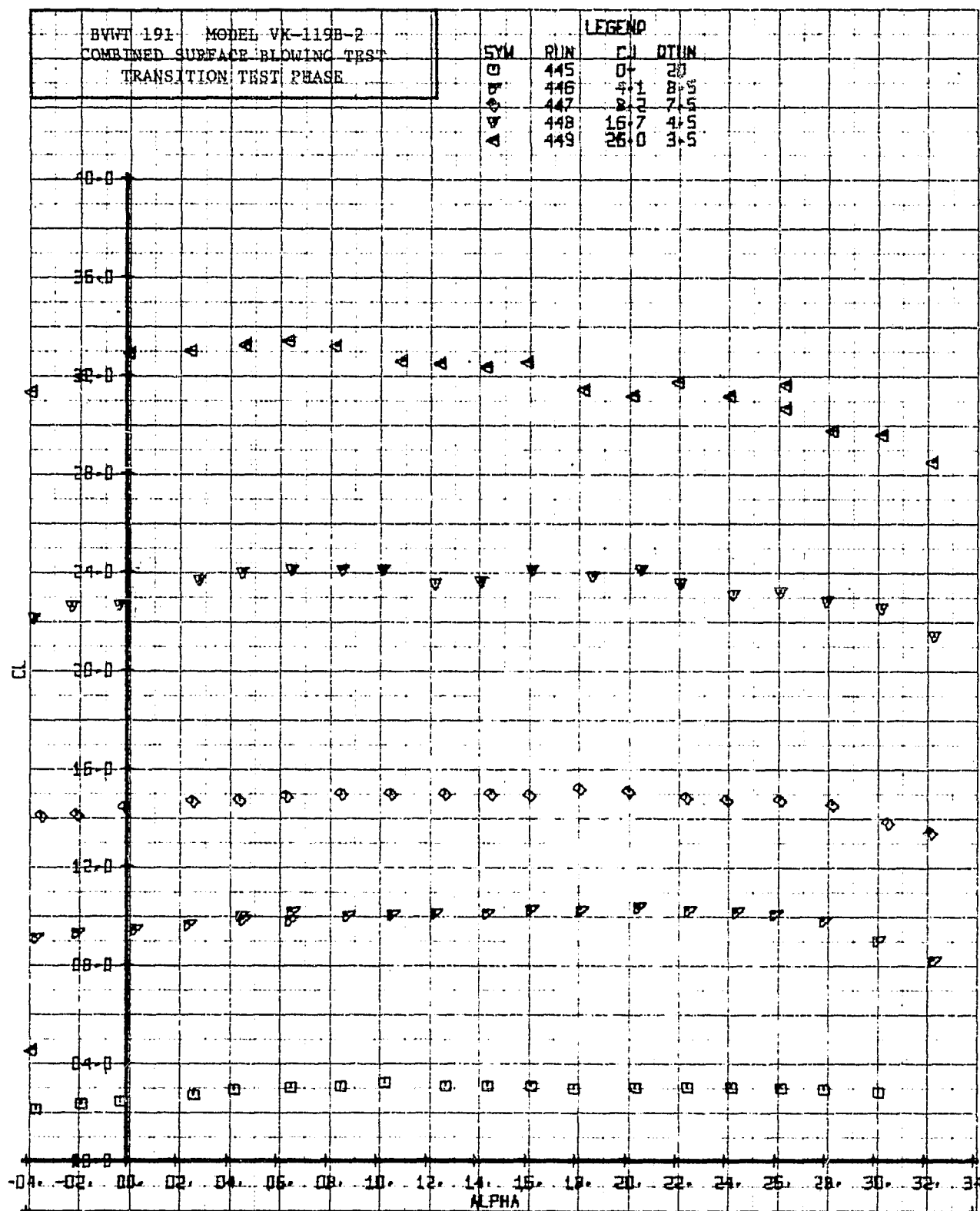


Figure 7.3-17. Retracted-Wing Performance with $\delta_f = 90^\circ/75^\circ$
a. $C_L - \alpha$

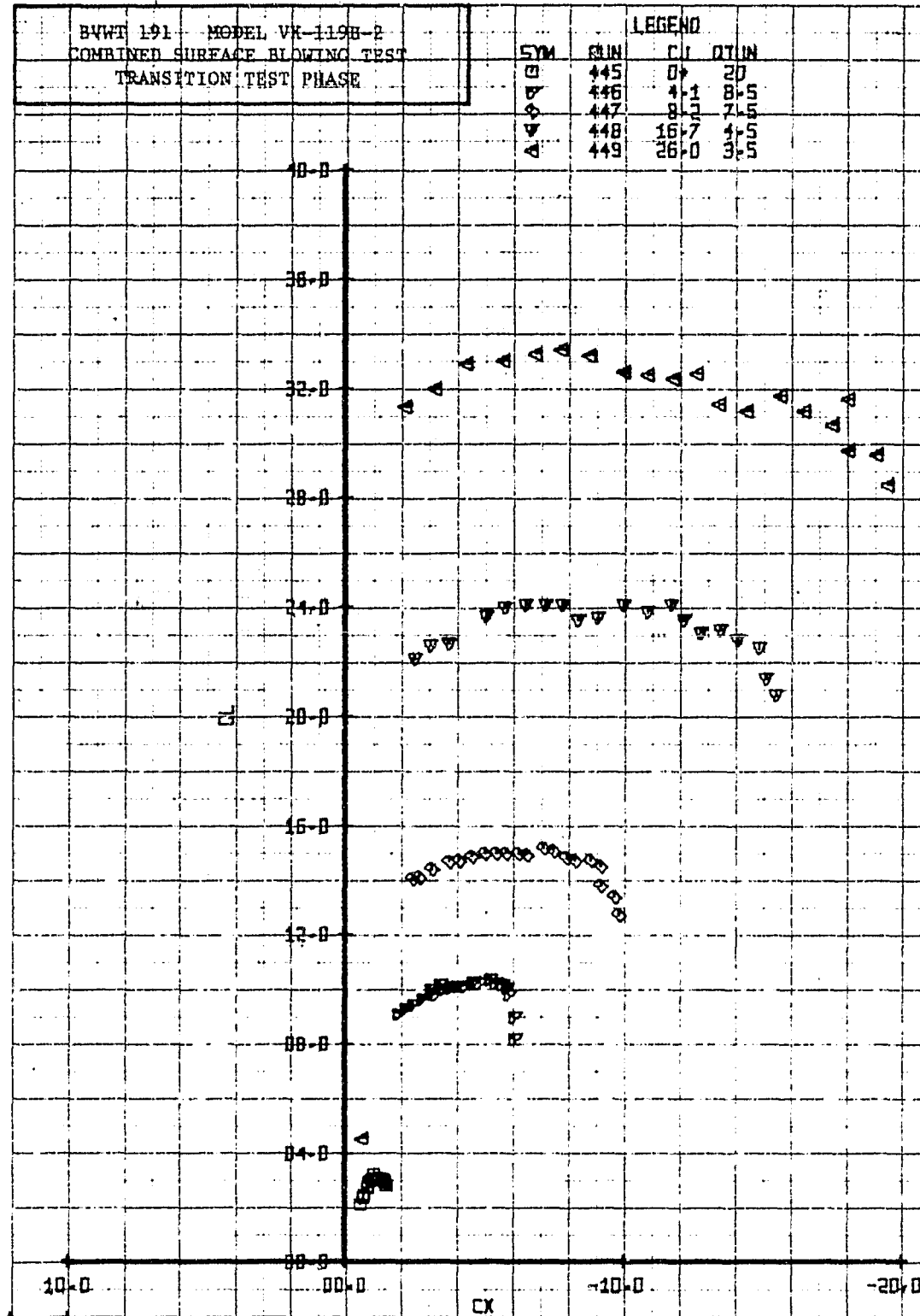


Figure 7.3-17. Retracted-Wing Performance with $\delta_f = 90^\circ/75^\circ$
b. $C_L - C_X$

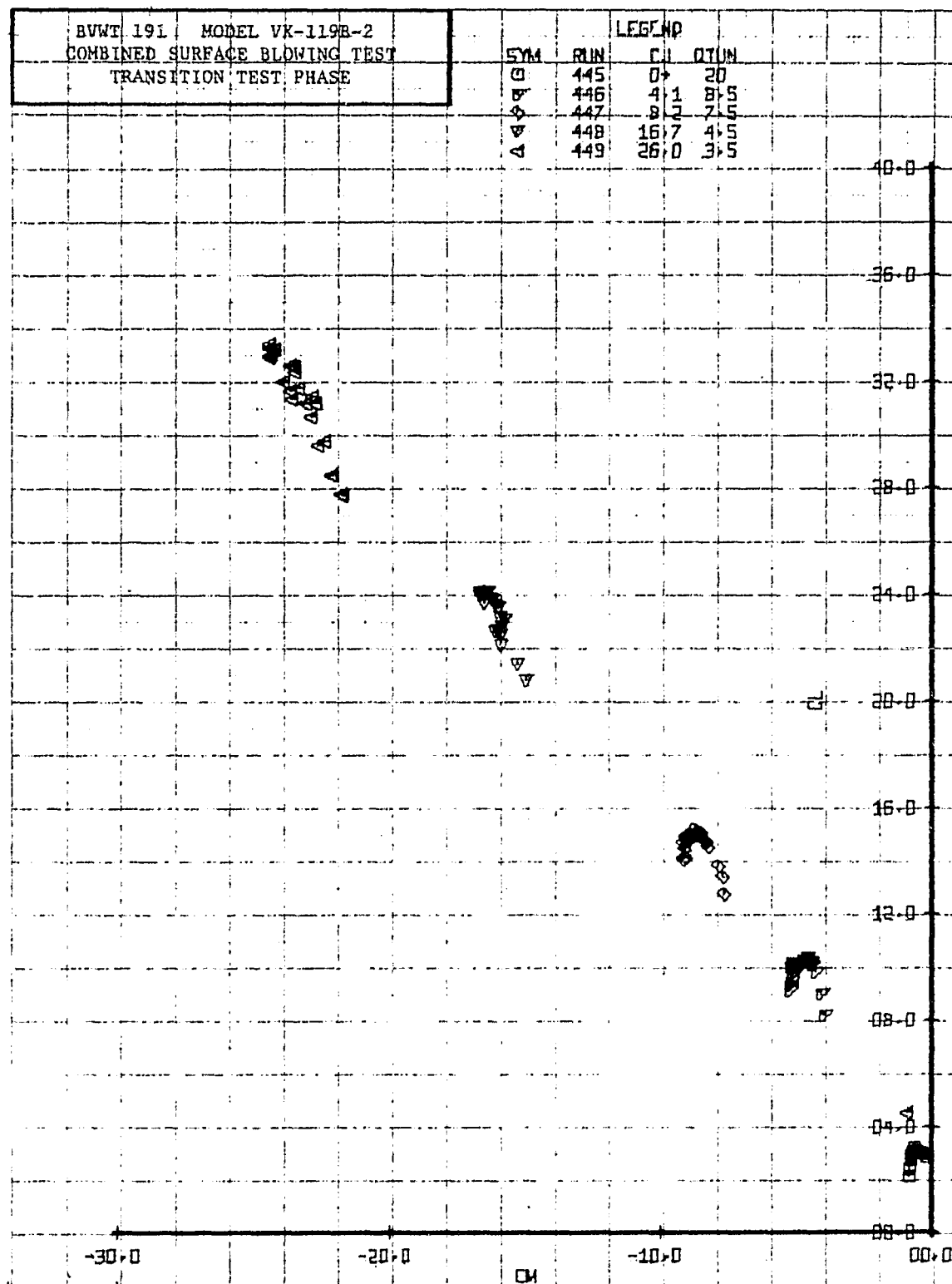


Figure 7.3-17. Retracted-Wing Performance with $\delta_f = 90^\circ/75^\circ$
c. $C_L - C_m$

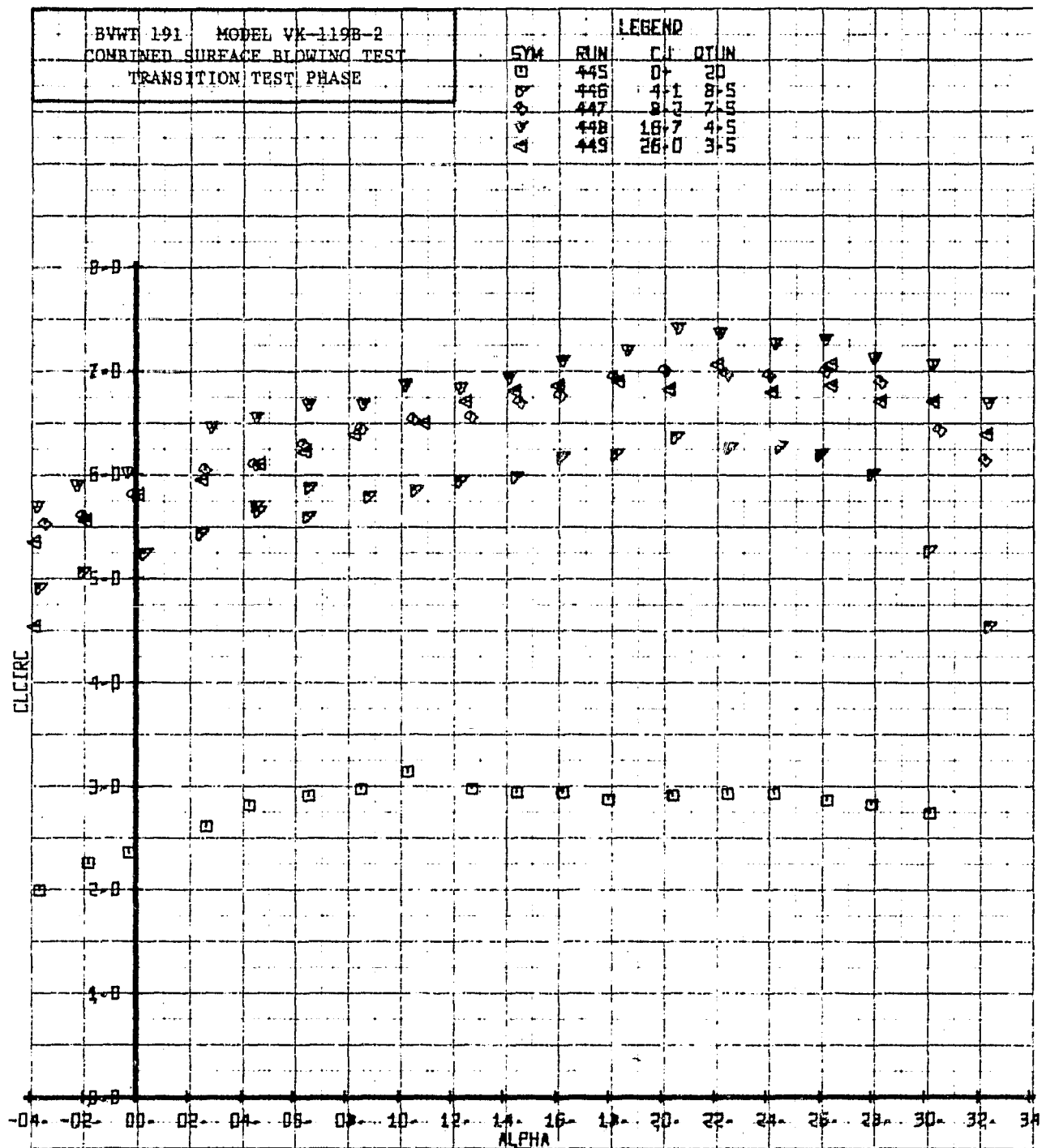


Figure 7.3-17. Retracted-Wing Performance with $\delta_f = 90^\circ/75^\circ$
d. $C_{LCIRC} - \alpha$

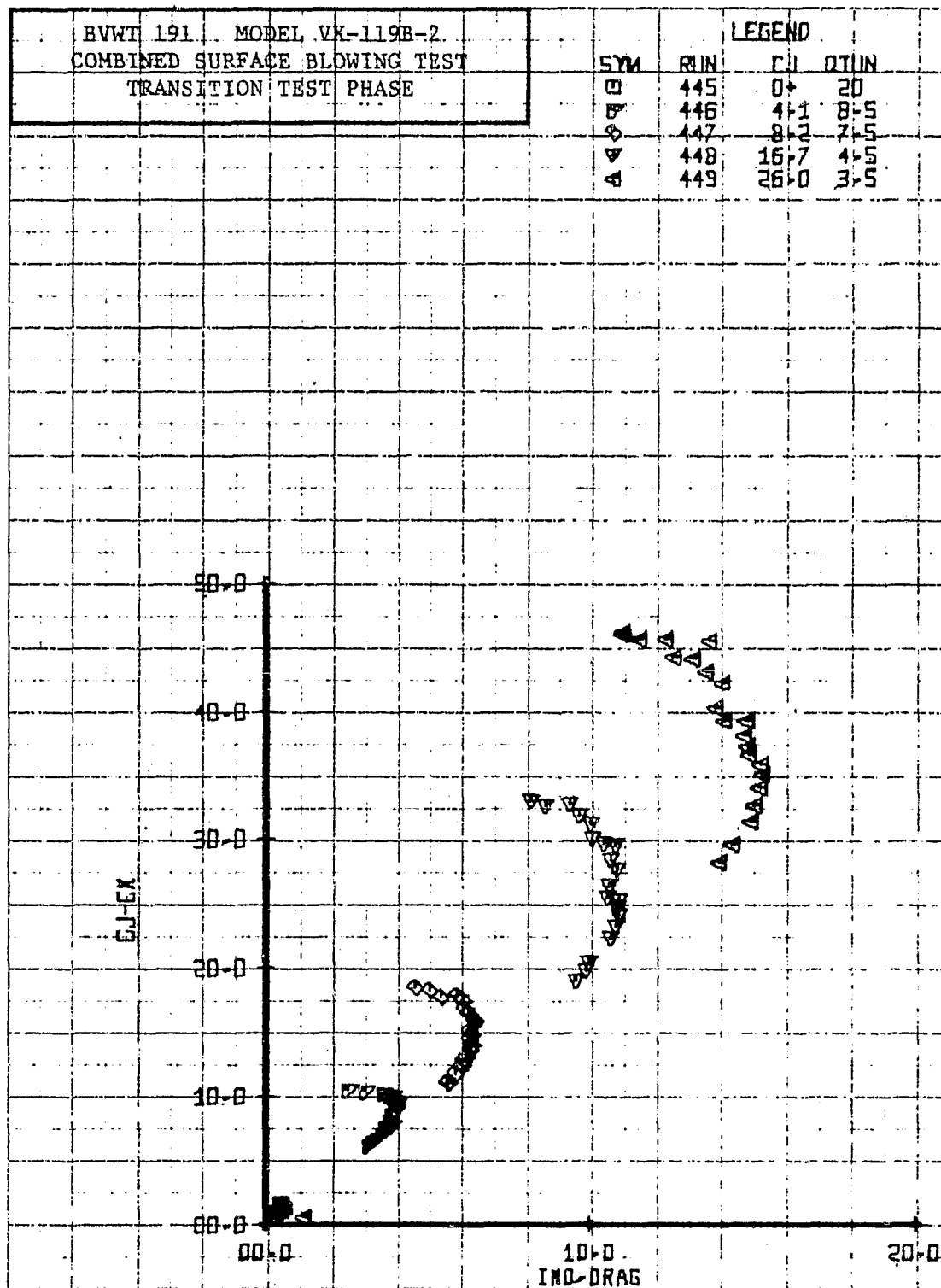


Figure 7.3-17. Retracted-Wing Performance with $\delta_f = 90^\circ/75^\circ$
e. Induced Drag

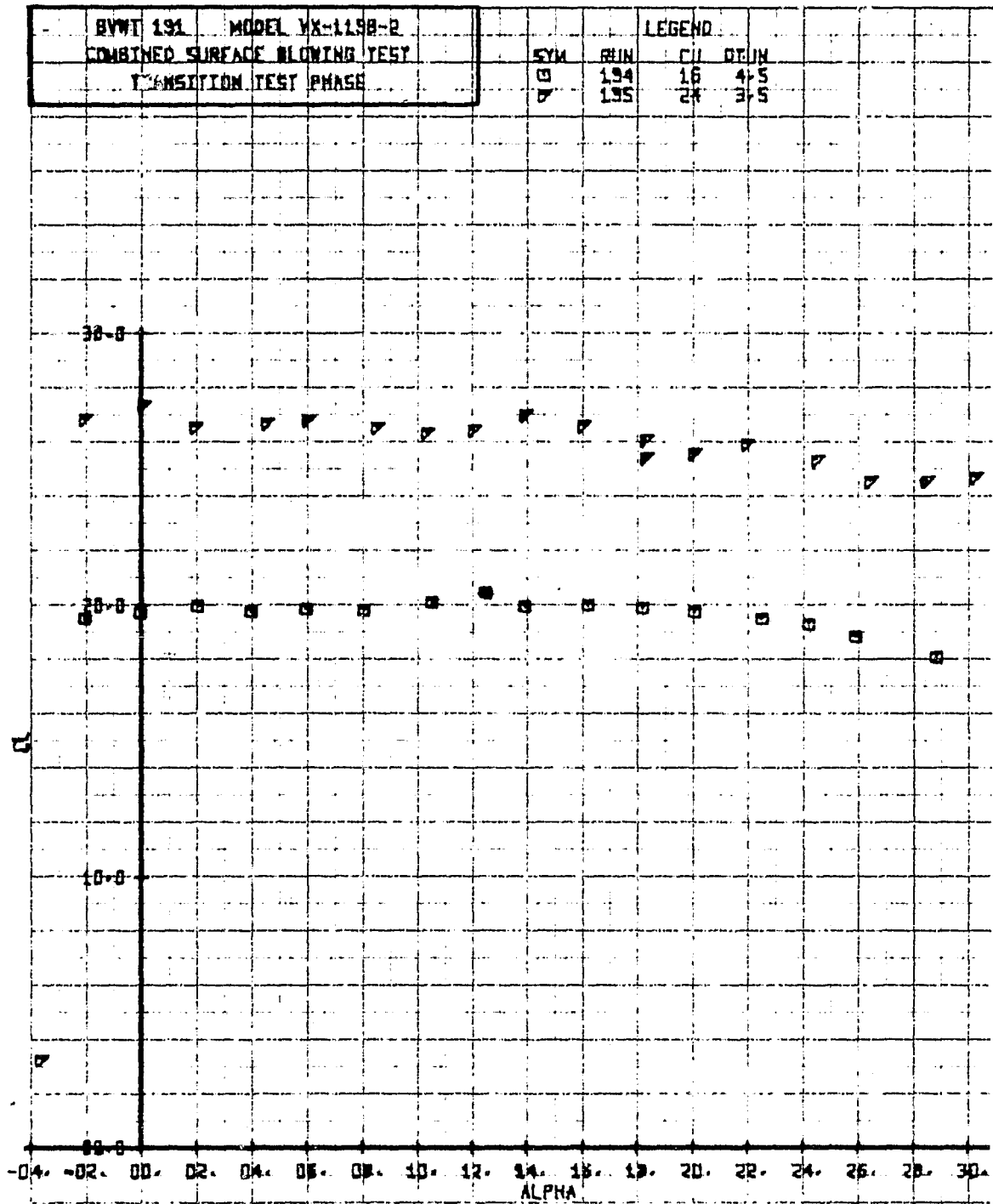


Figure 7.3-18. Retracted-Wing Performance with $\delta_f = 100^\circ/75^\circ$
a. $C_L - \alpha$

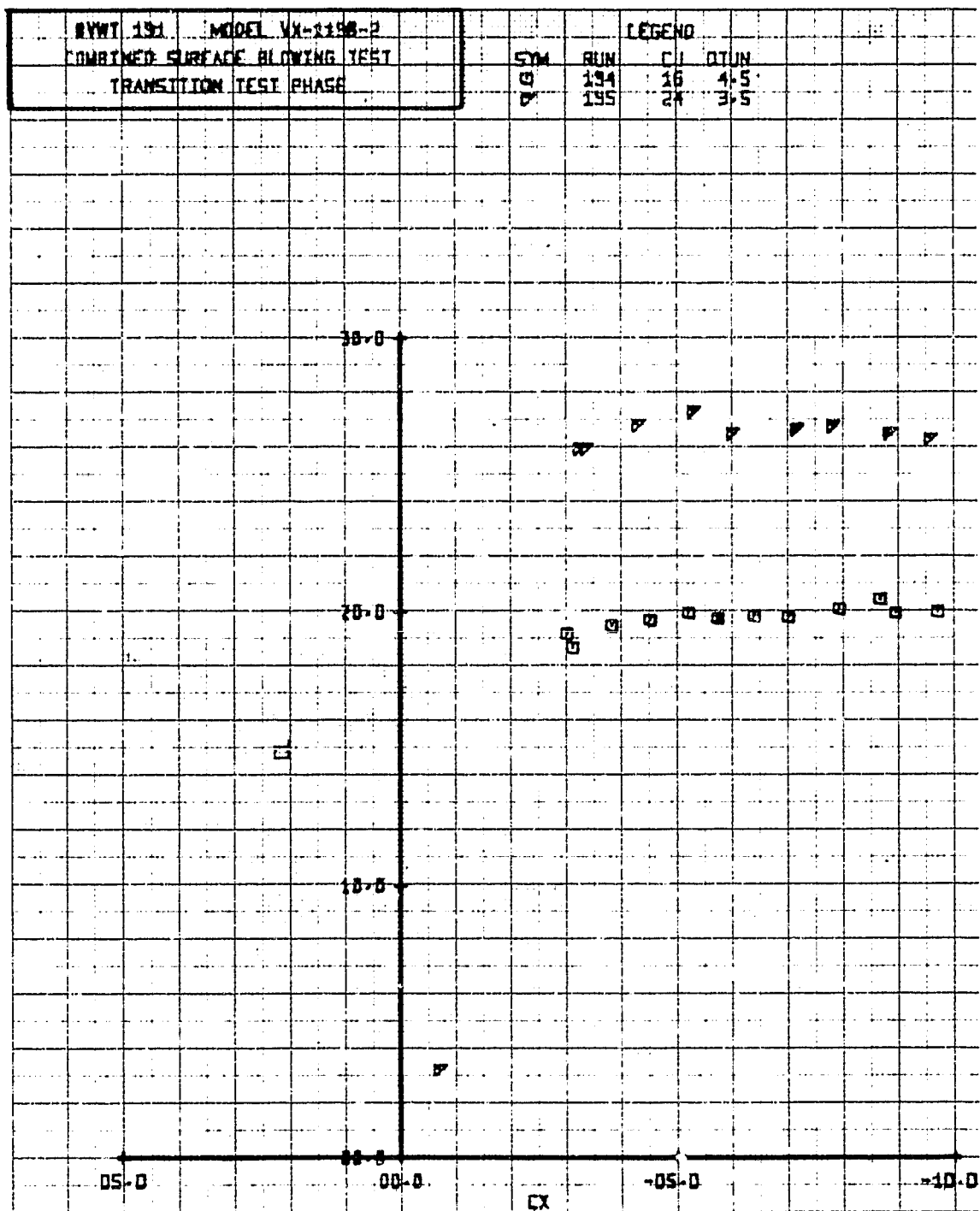


Figure 7.3-18. Retracted-Wing Performance with $\delta_f = 100^\circ/75^\circ$
 b. $C_L - C_X$

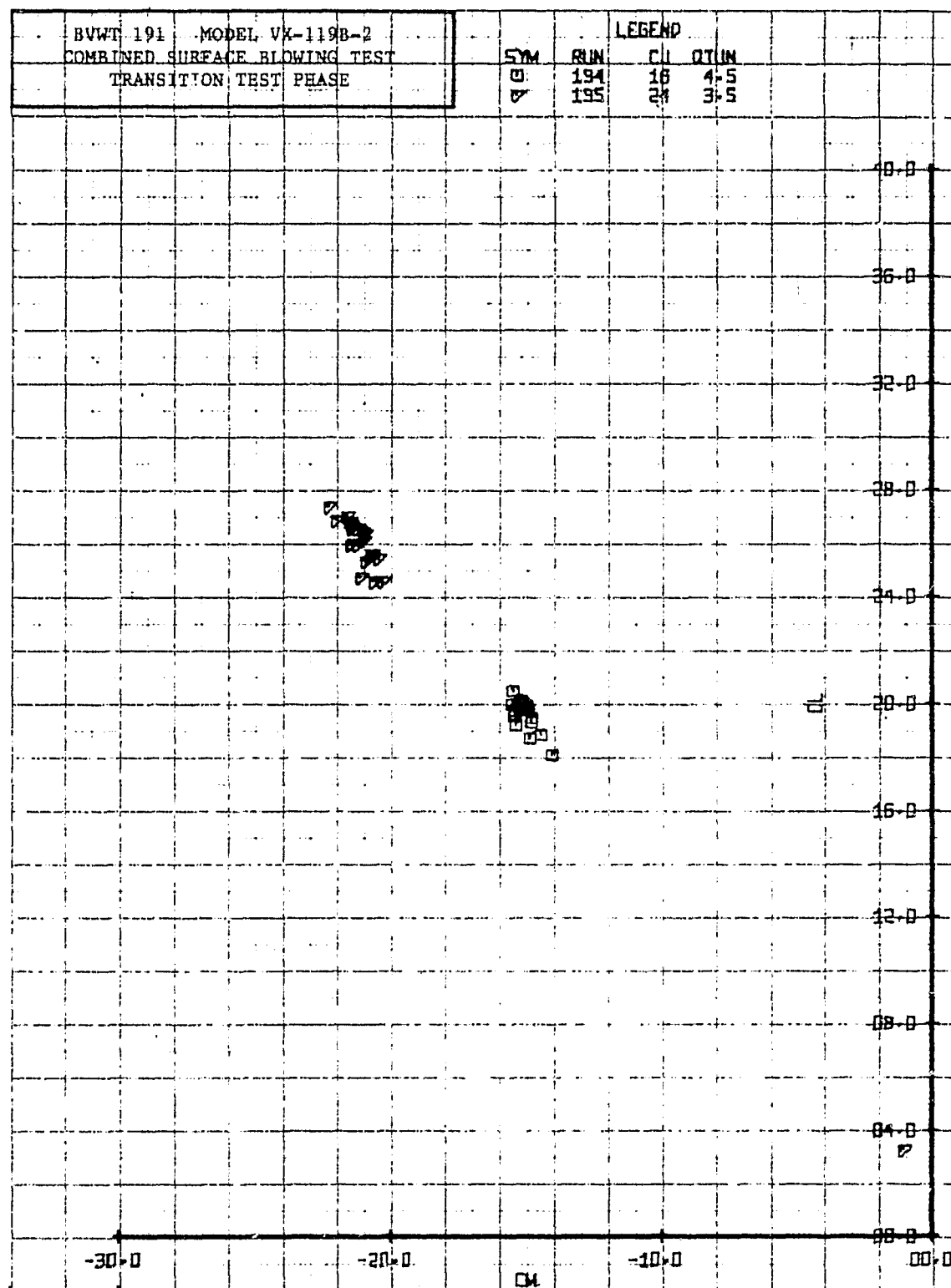


Figure 7.3-18. Retracted-Wing Performance with $\delta_f = 100^\circ/75^\circ$
c. $C_L - C_m$

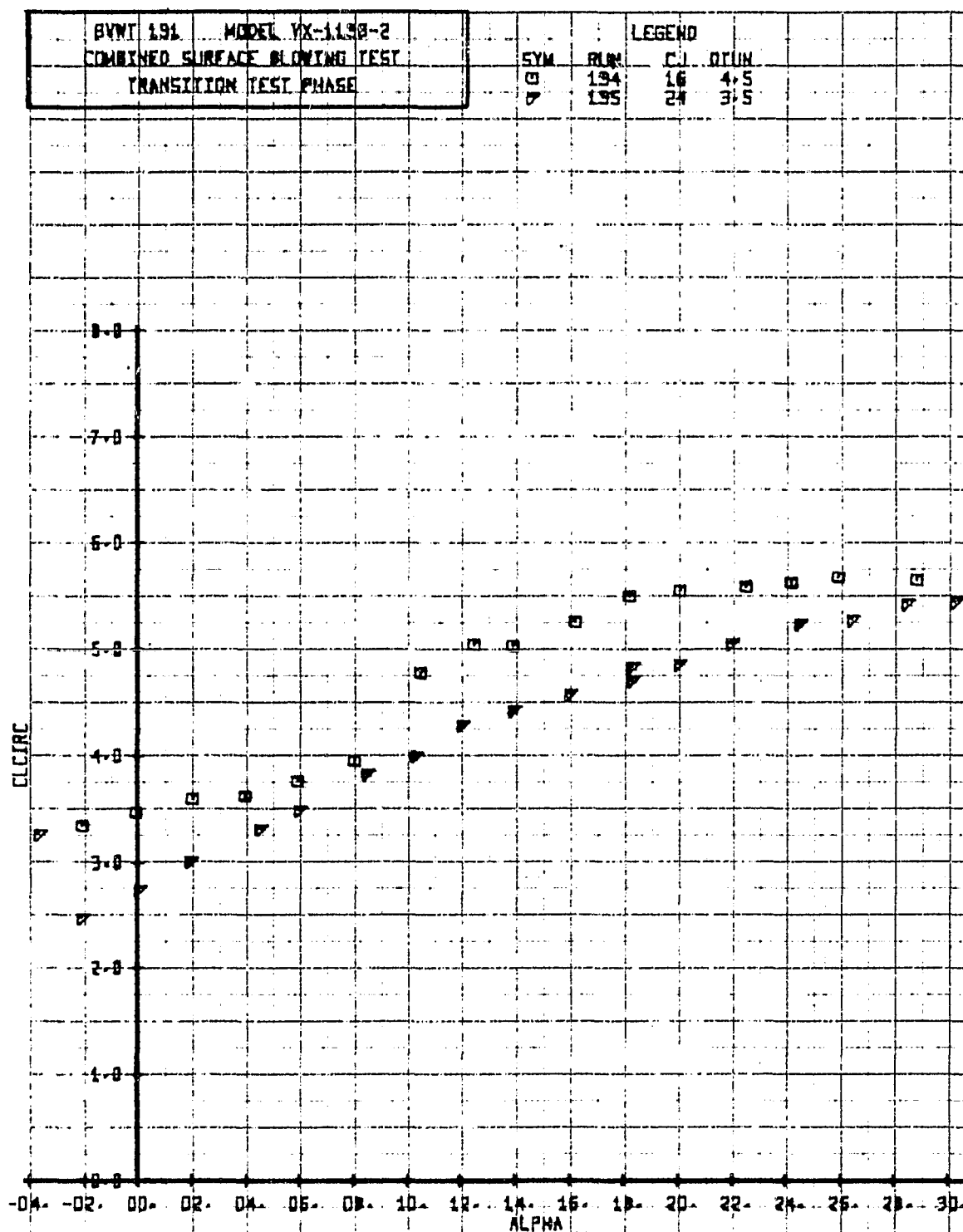


Figure 7.3-18. Retracted-Wing Performance with $\delta_f = 100^\circ/75^\circ$
d. $C_{LCIRC} - \alpha$

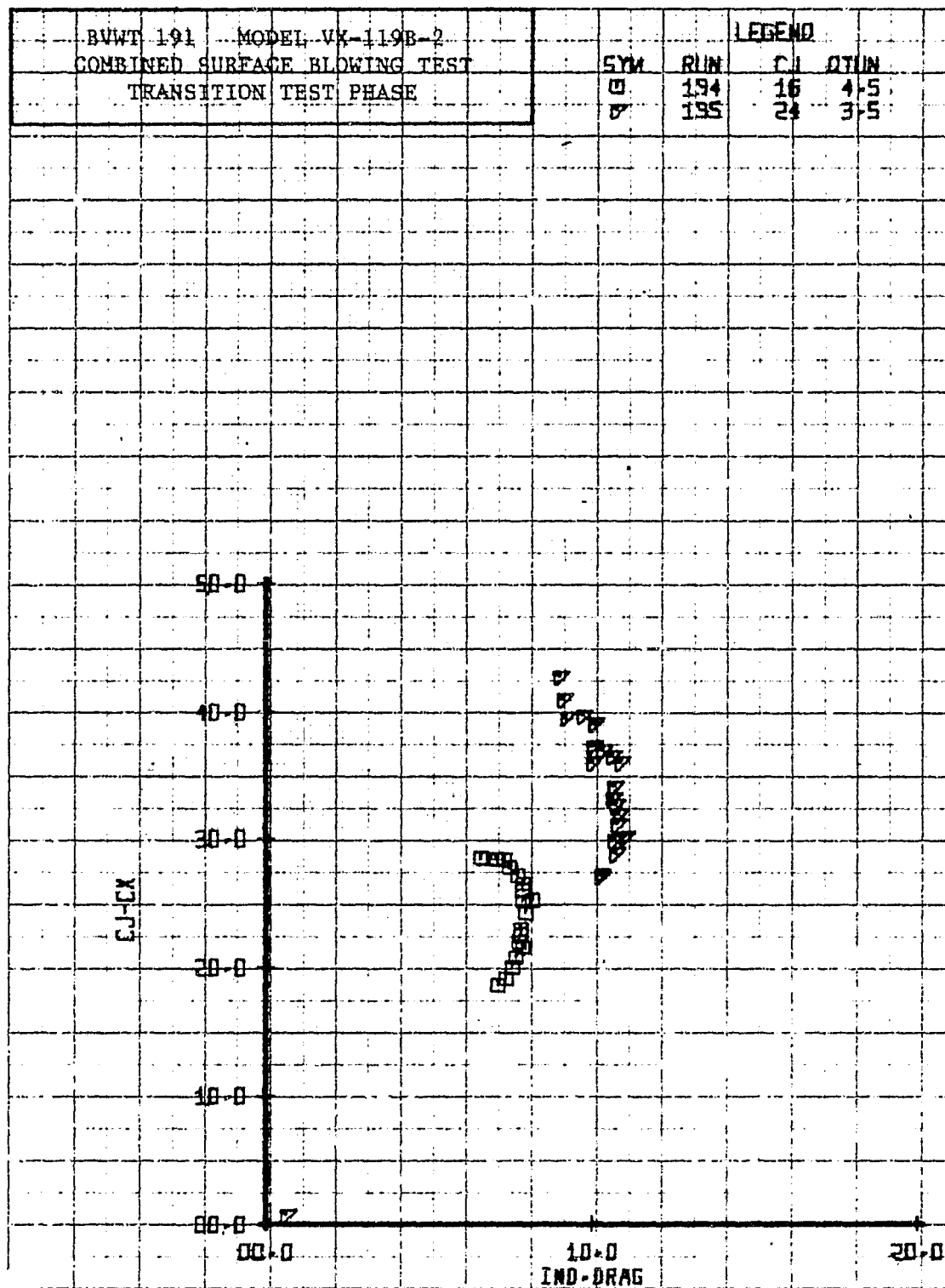


Figure 7.3-18. Retracted-Wing Performance with $\delta_f = 100^\circ/75^\circ$
e. Induced Drag

$$\alpha = 0^\circ$$

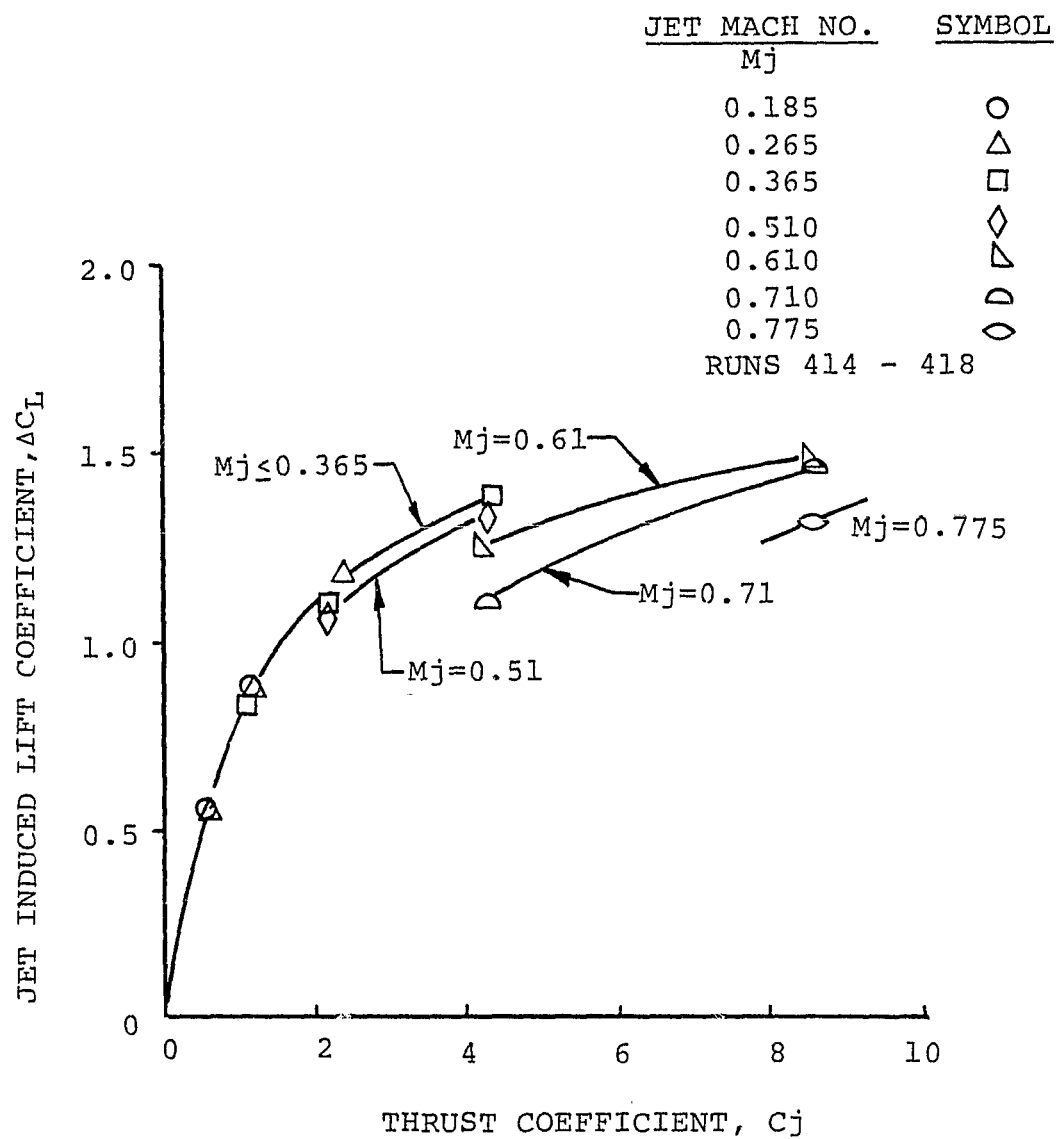


Figure 7.3-19. Jet-Induced Lift at $\delta_f = 45^\circ$, Retracted Wing

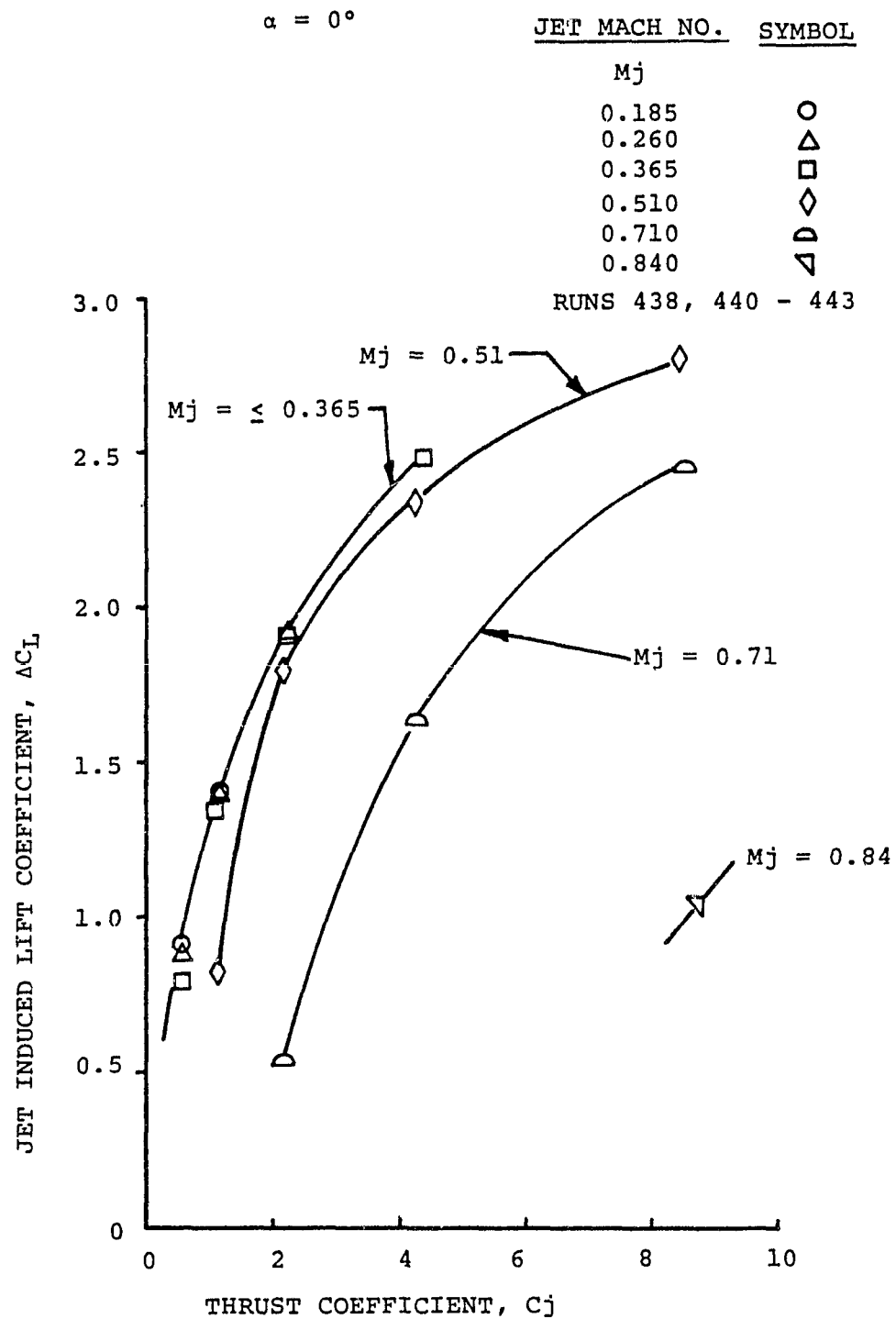


Figure 7.3-20. Jet-Induced Lift at $\delta_f = 60^\circ$, Retracted Wing

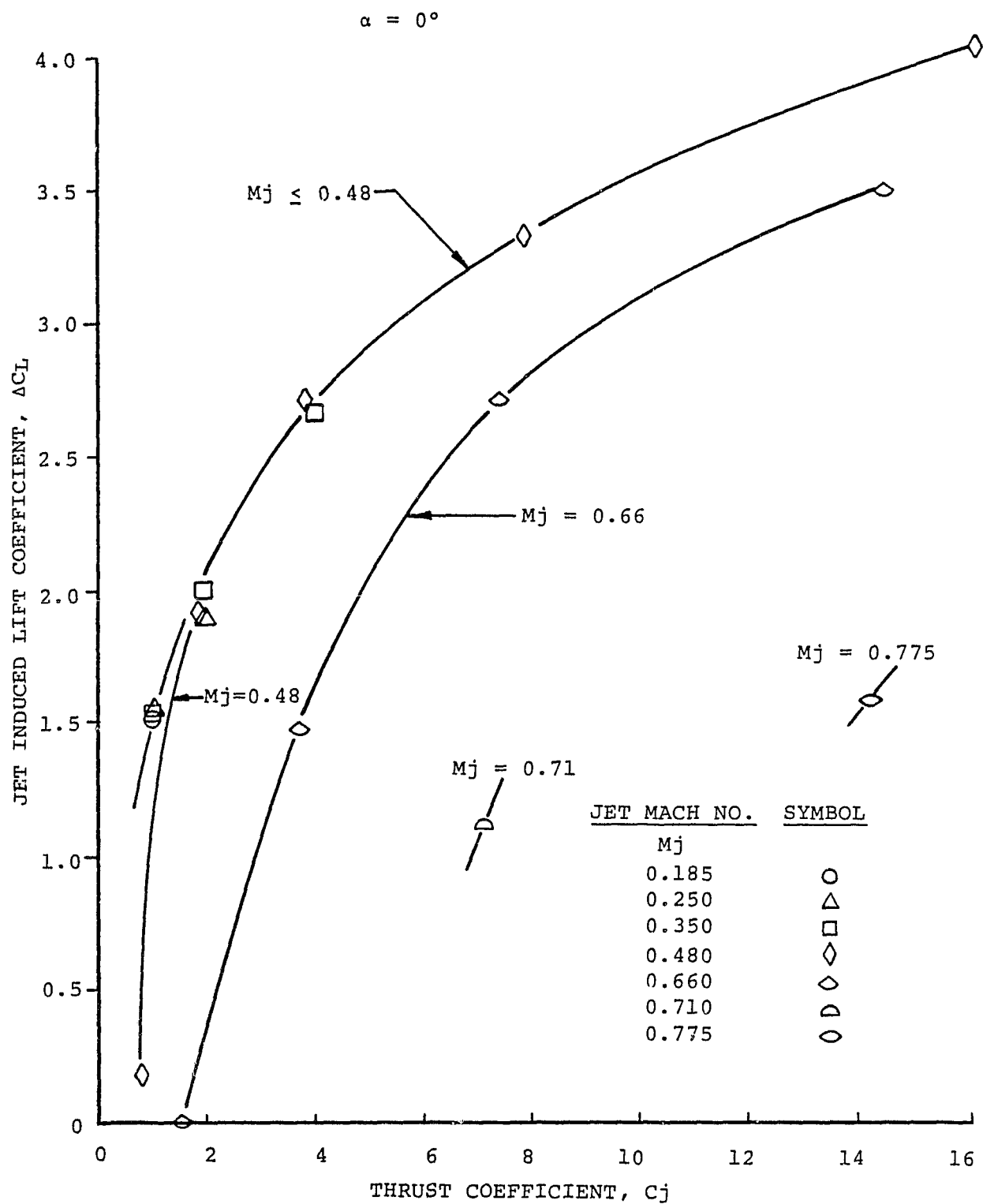


Figure 7.3-21. Jet-Induced Lift at $\delta_f = 75^\circ$, Retracted Wing

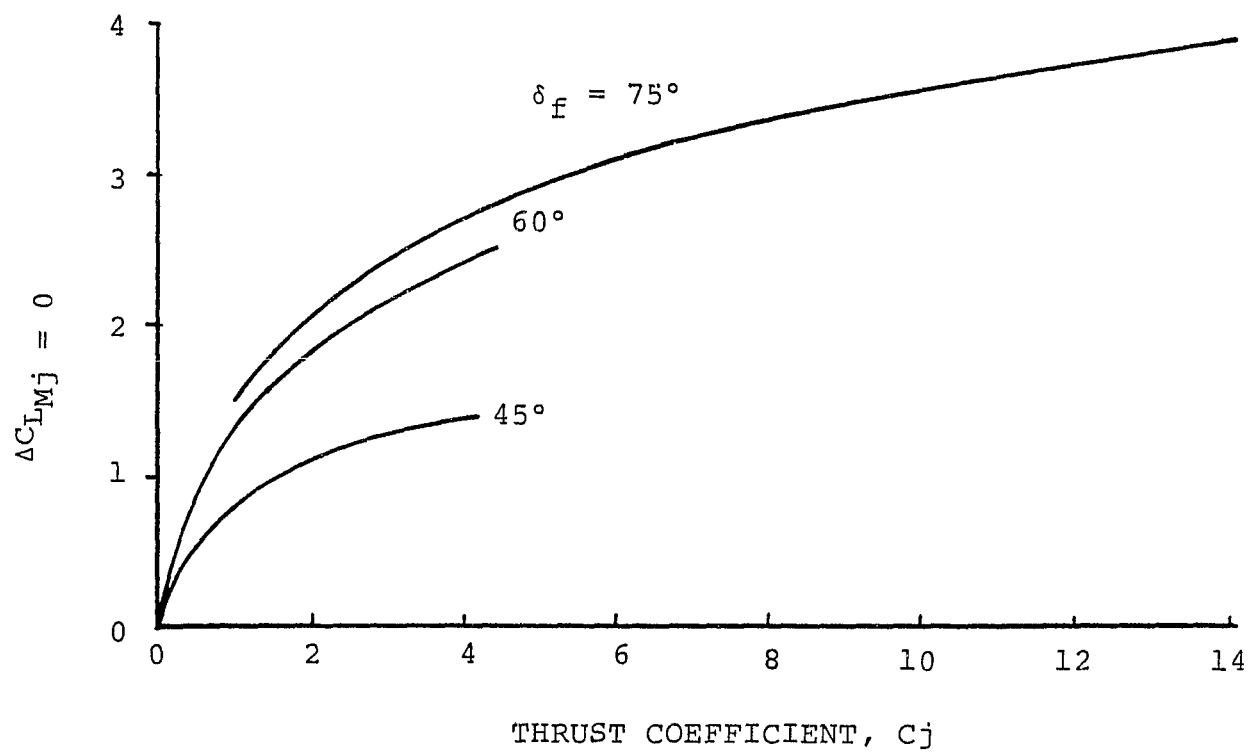


Figure 7.3-22. Jet-Induced Lift for Low Jet Mach Number, Retracted Wing

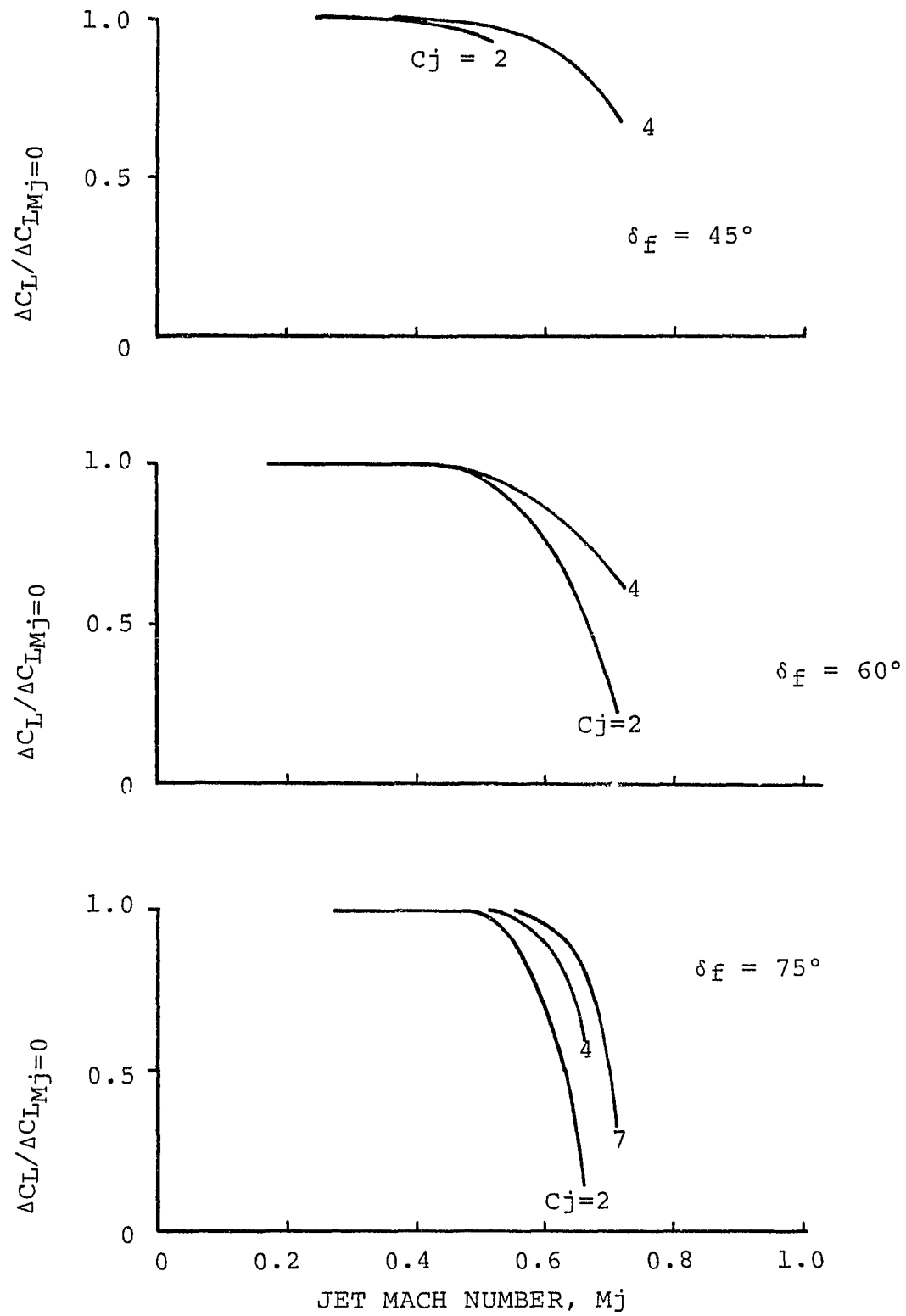


Figure 7.3-23. Effect of Jet Mach Number on Induced Lift, Retracted Wing

THEORY OF REFERENCE 3

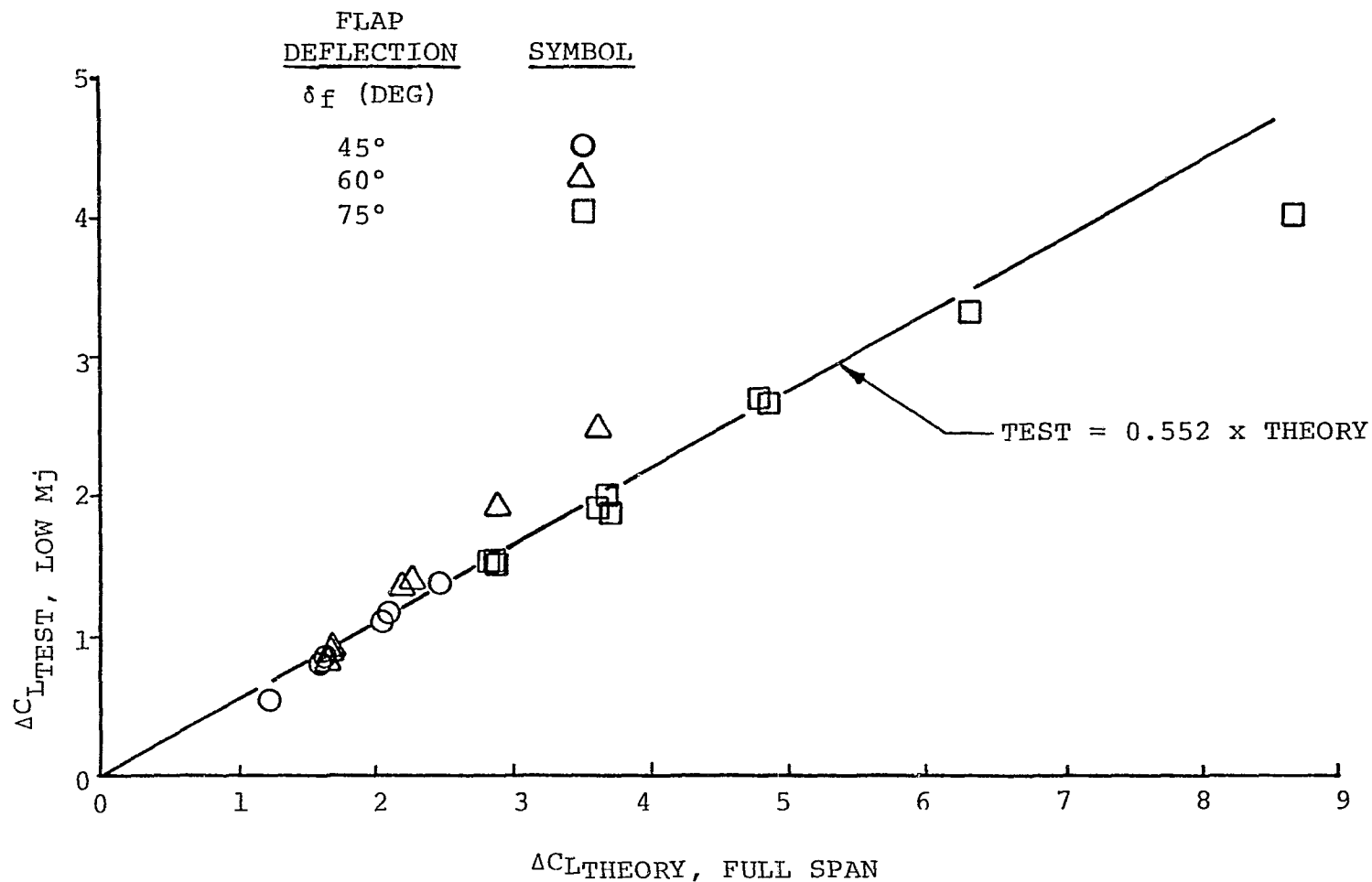


Figure 7.3-24. Jet-Induced Lift – Comparison of Test and Theory, Retracted Wing

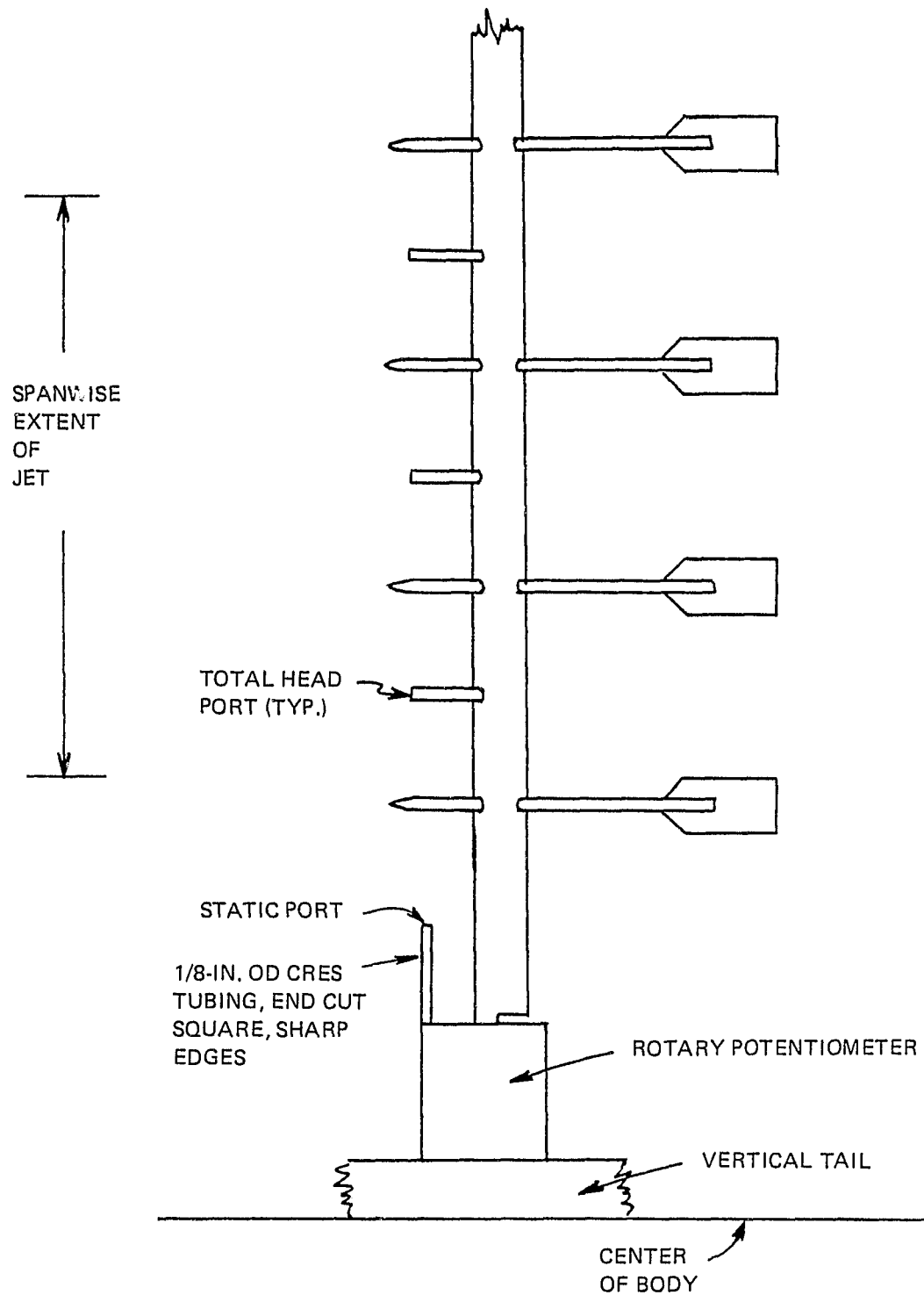


Figure 7.3-25. Downwash Rake

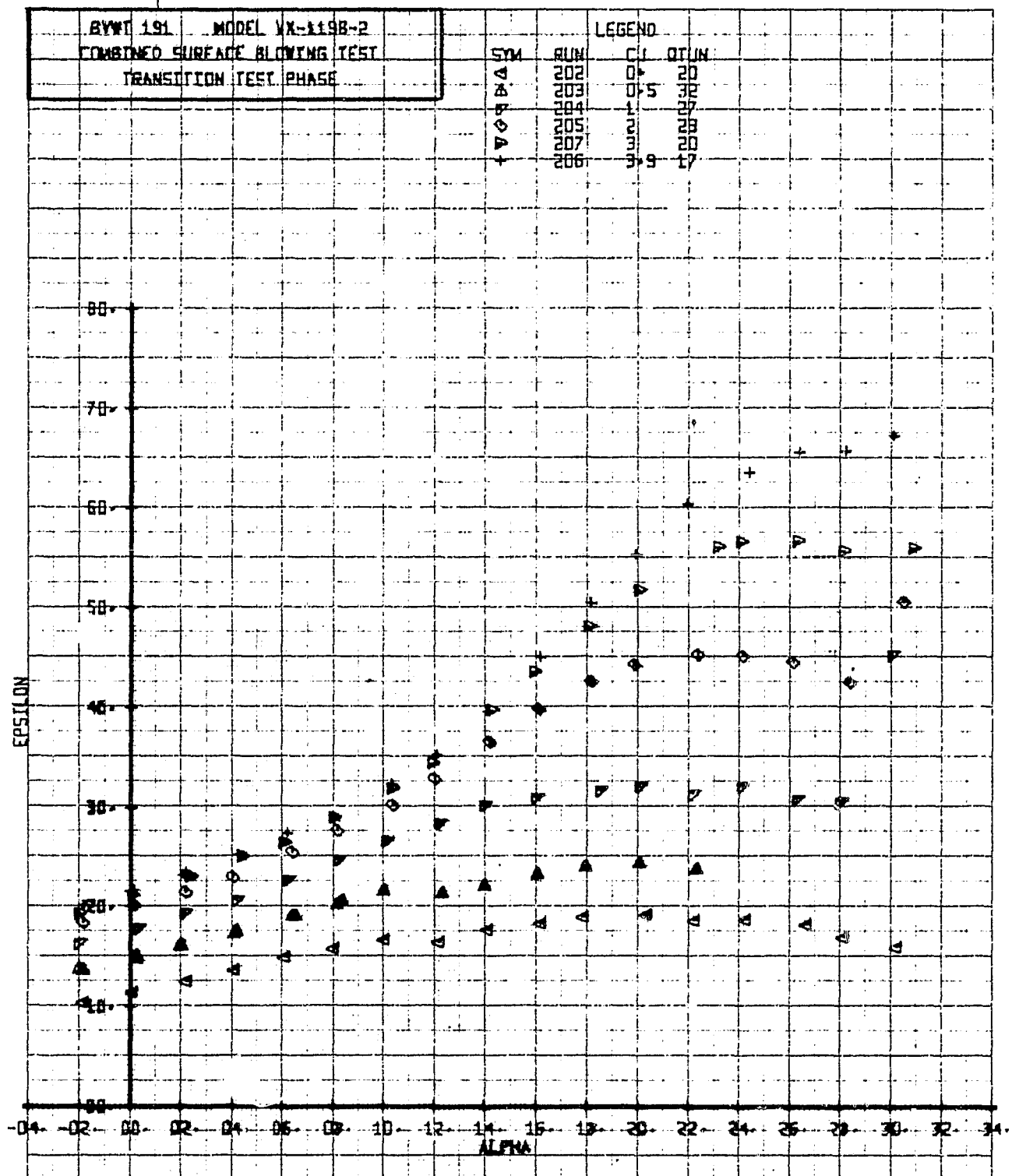


Figure 7.3-26. Retracted-Wing Downwash Characteristics with $\delta_f = 45^\circ$

a. $\epsilon - \alpha$

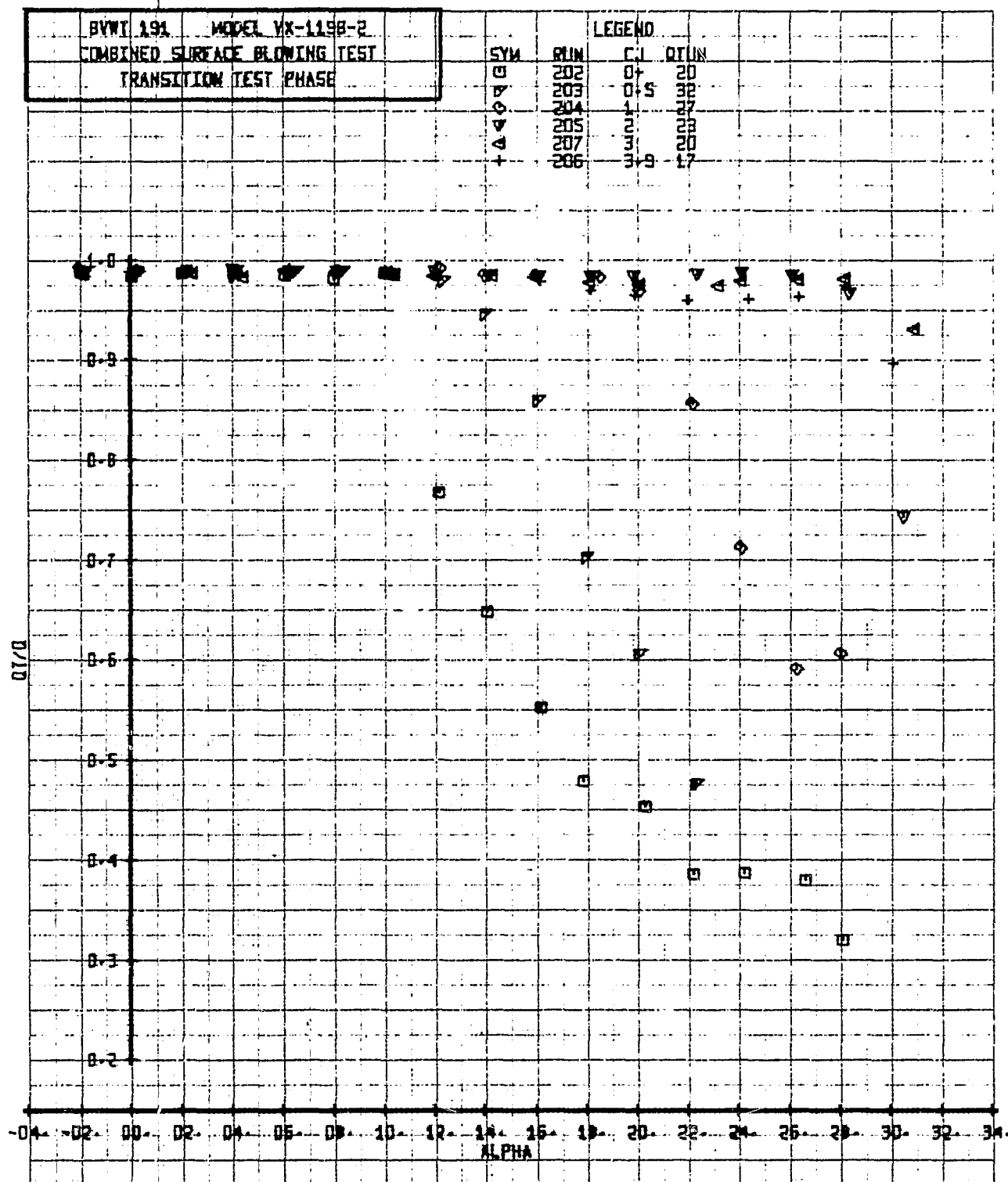


Figure 7.3-26. Retracted-Wing Downwash Characteristics with $\delta_f = 45^\circ$
 b. $q_t/q - \alpha$

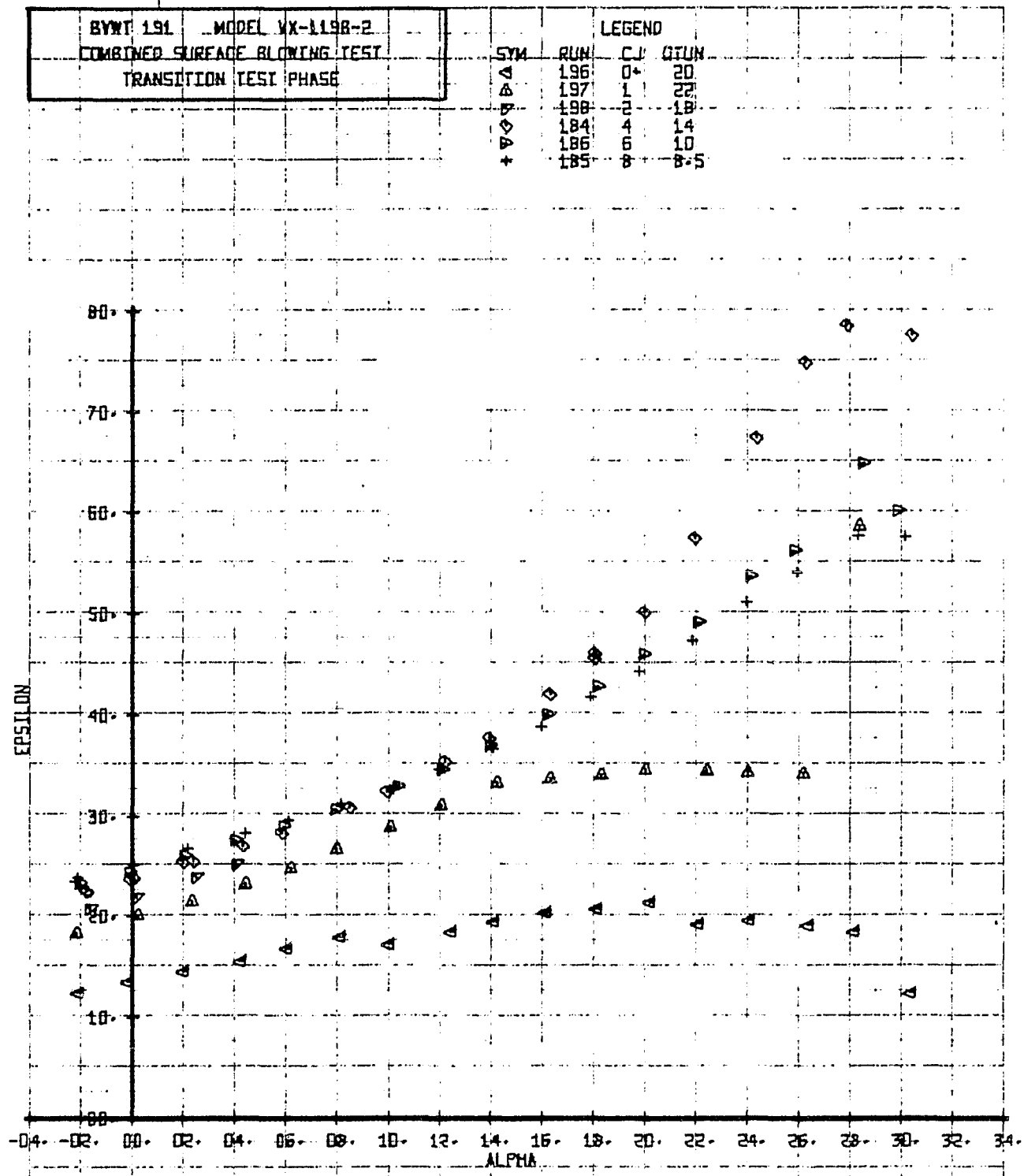


Figure 7.3-27. Retracted-Wing Downwash Characteristics with $\delta_f = 60^\circ$

a. $\epsilon - \alpha$

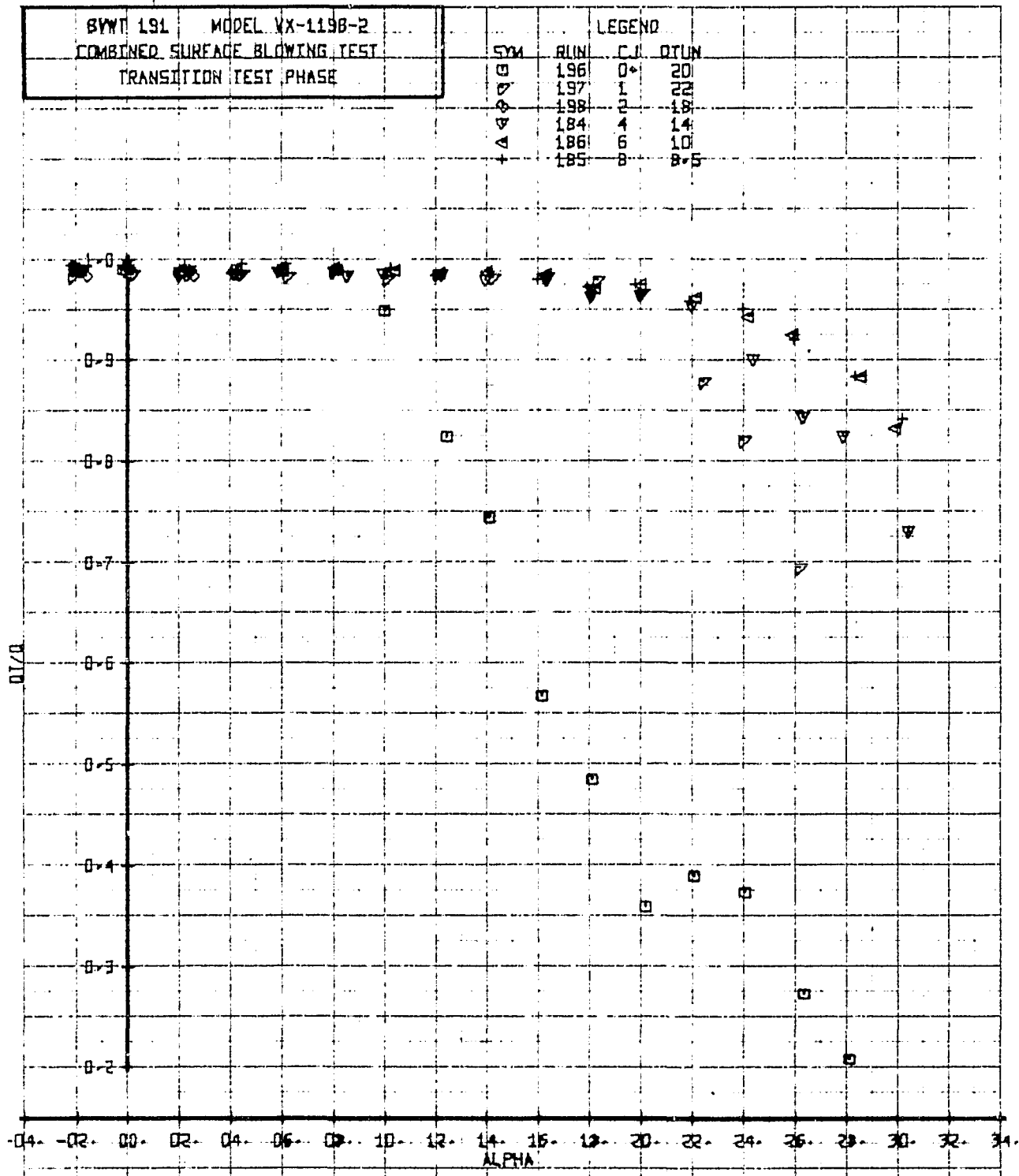


Figure 7.3-27. Retracted-Wing Downwash Characteristics with $\delta_f = 60^\circ$

b. $qt/q - \alpha$

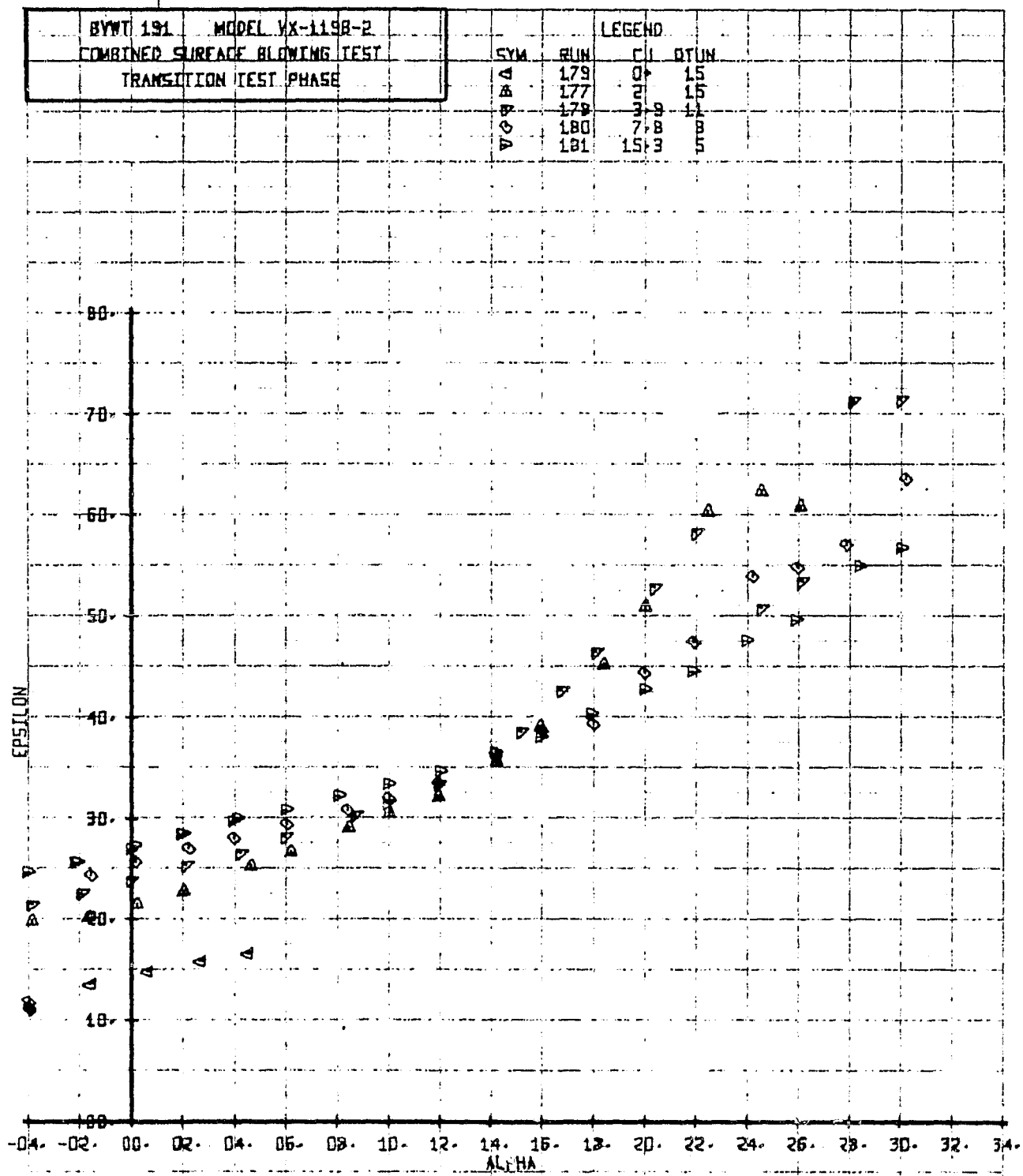


Figure 7.3-28. Retracted-Wing Downwash Characteristics with $\delta_f = 75^\circ$, $\epsilon - \alpha$

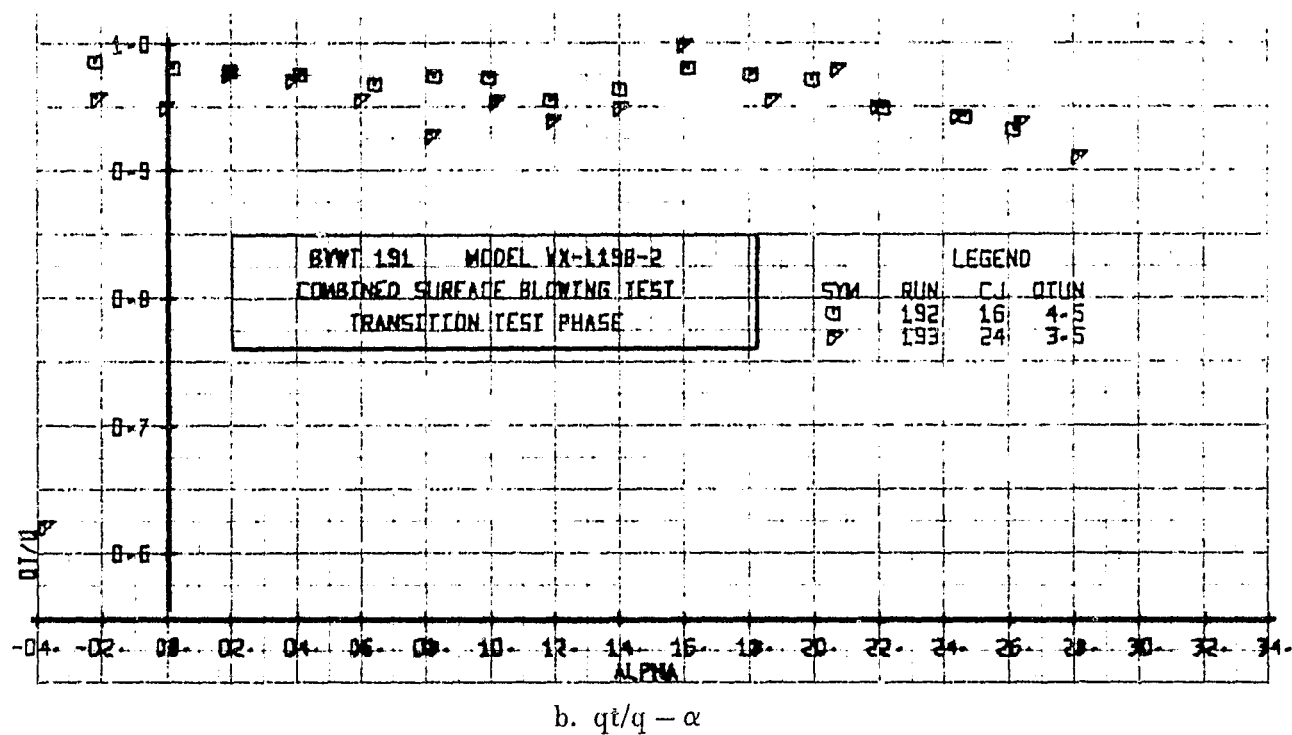
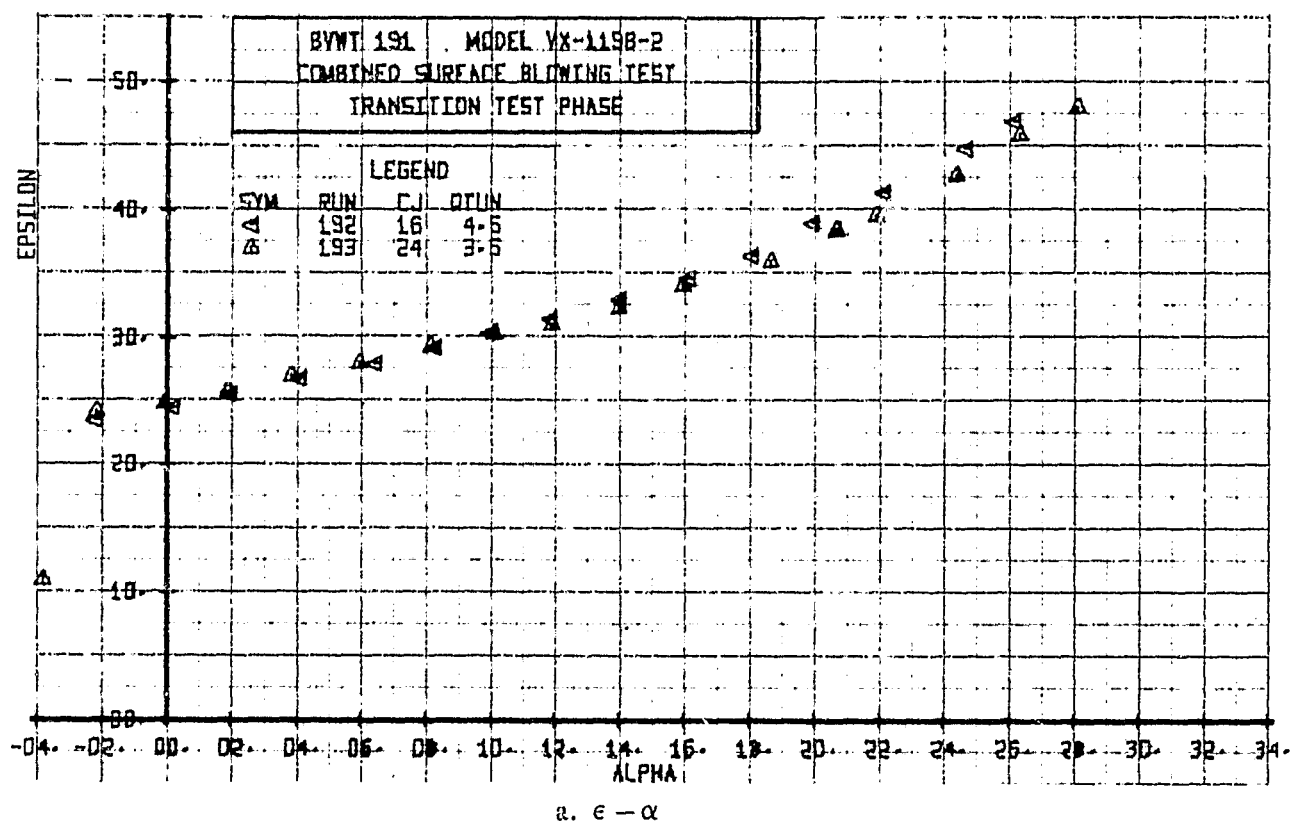


Figure 7.3-29. Retracted-Wing Downwash Characteristics with $\delta_f = 90^\circ/45^\circ$

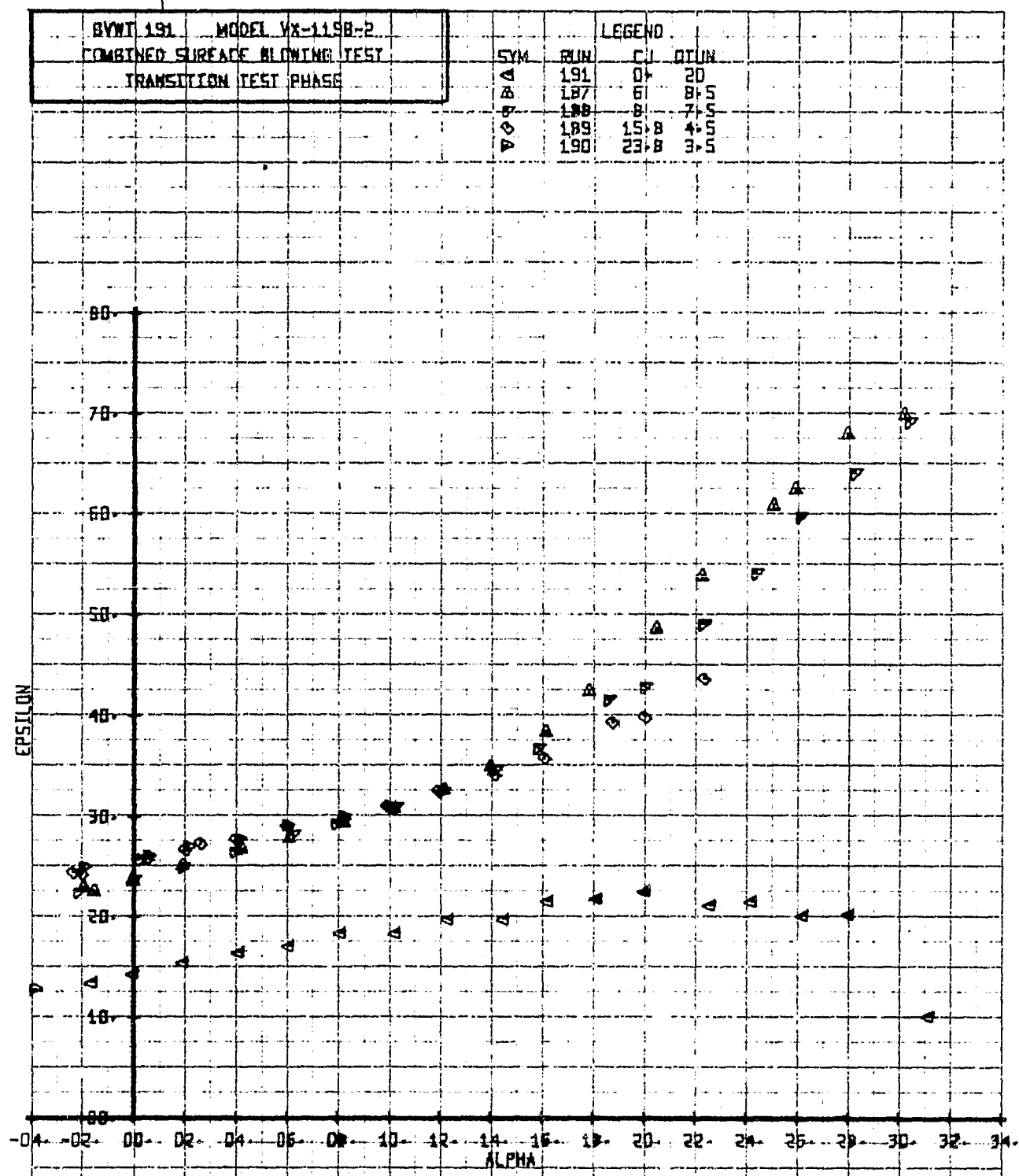


Figure 7.3-30. Retracted-Wing Downwash Characteristics with $\delta_f = 90^\circ/75^\circ$

a. $\epsilon - \alpha$

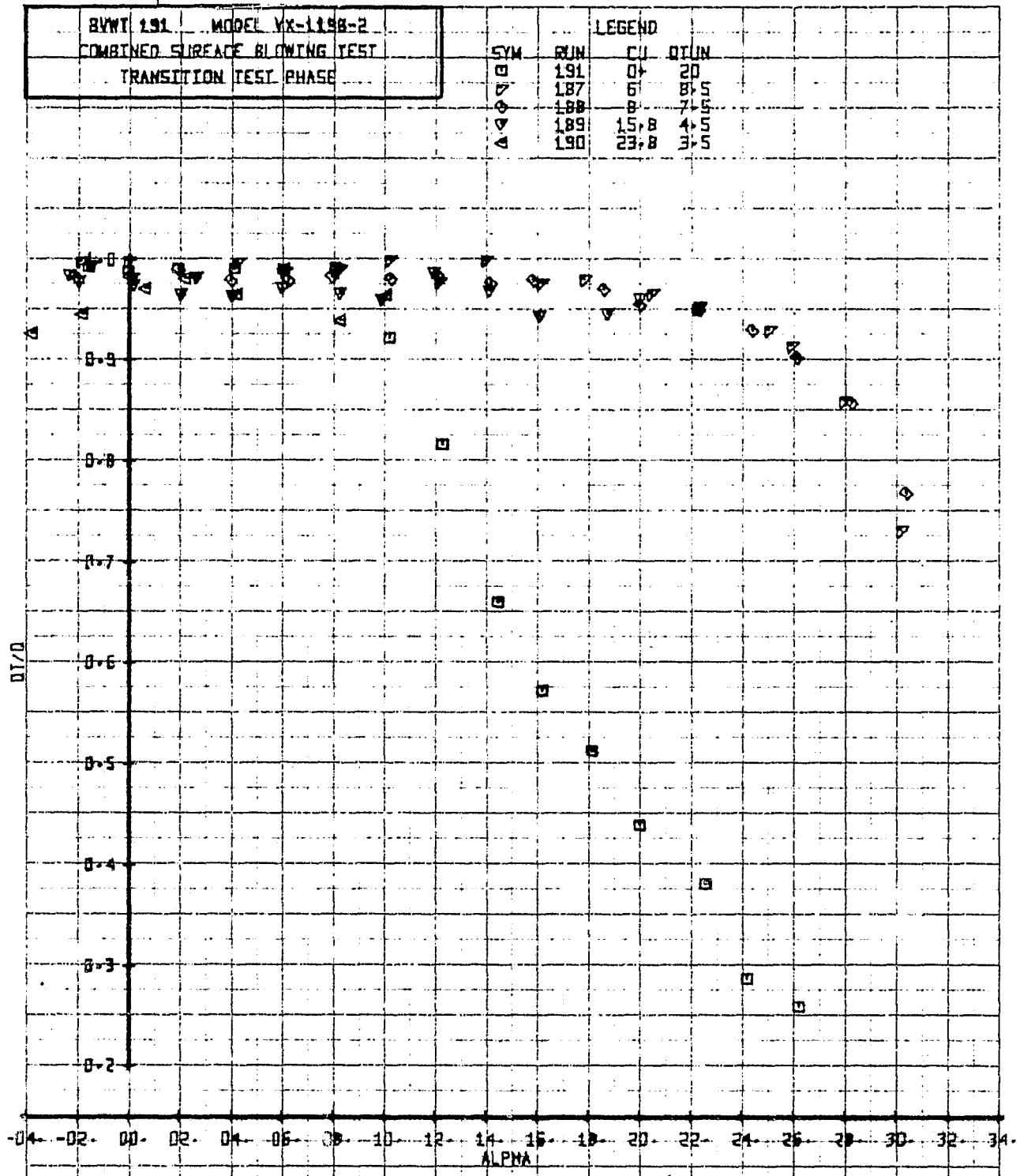


Figure 7.3-30. Retracted-Wing Downwash Characteristics with $\delta_f = 90^\circ/75^\circ$
 b. $qt/q - \alpha$

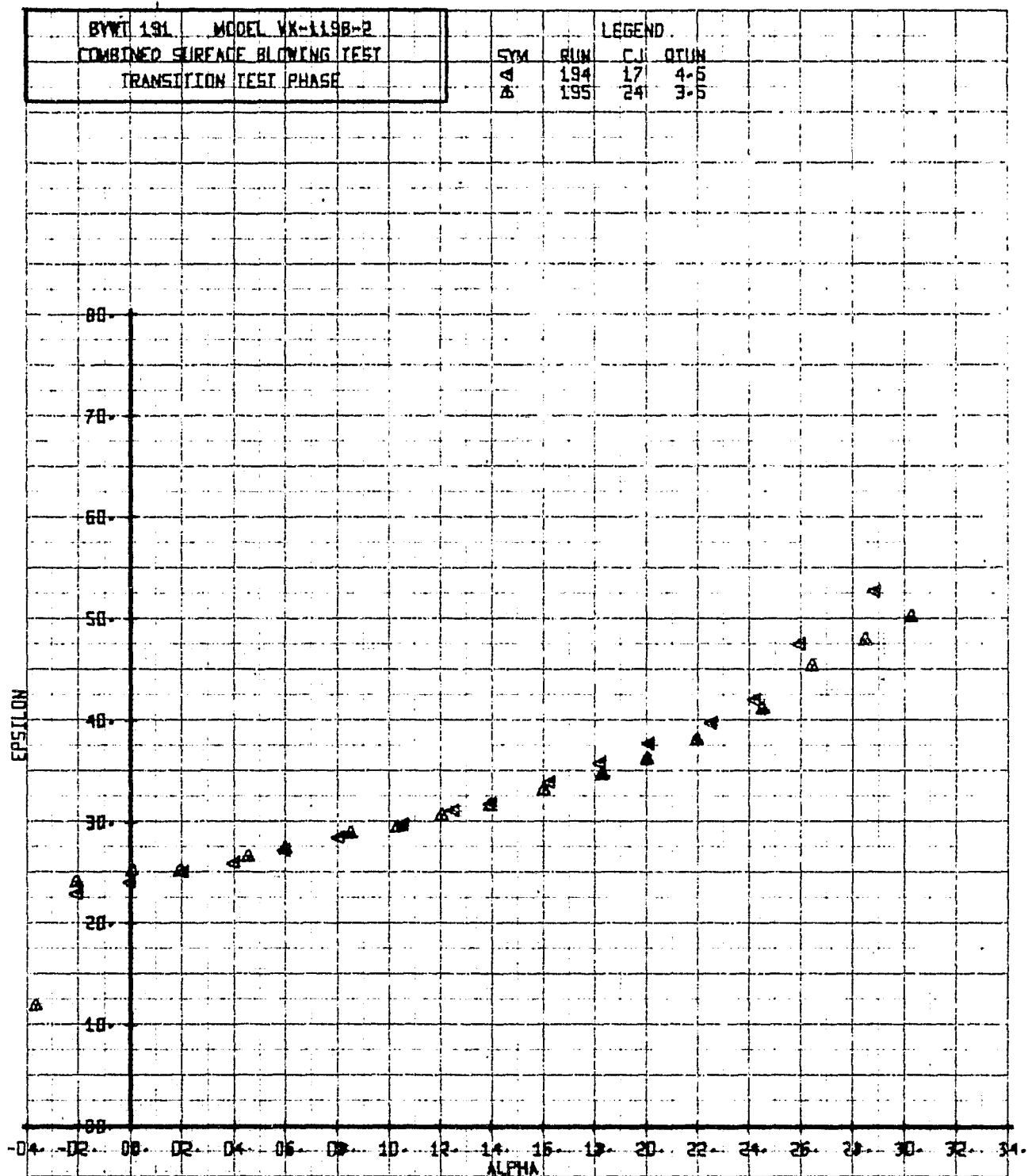


Figure 7.3-31. Retracted-Wing Downwash Characteristics with $\delta_f = 100^\circ/45^\circ$

a. $\epsilon - \alpha$

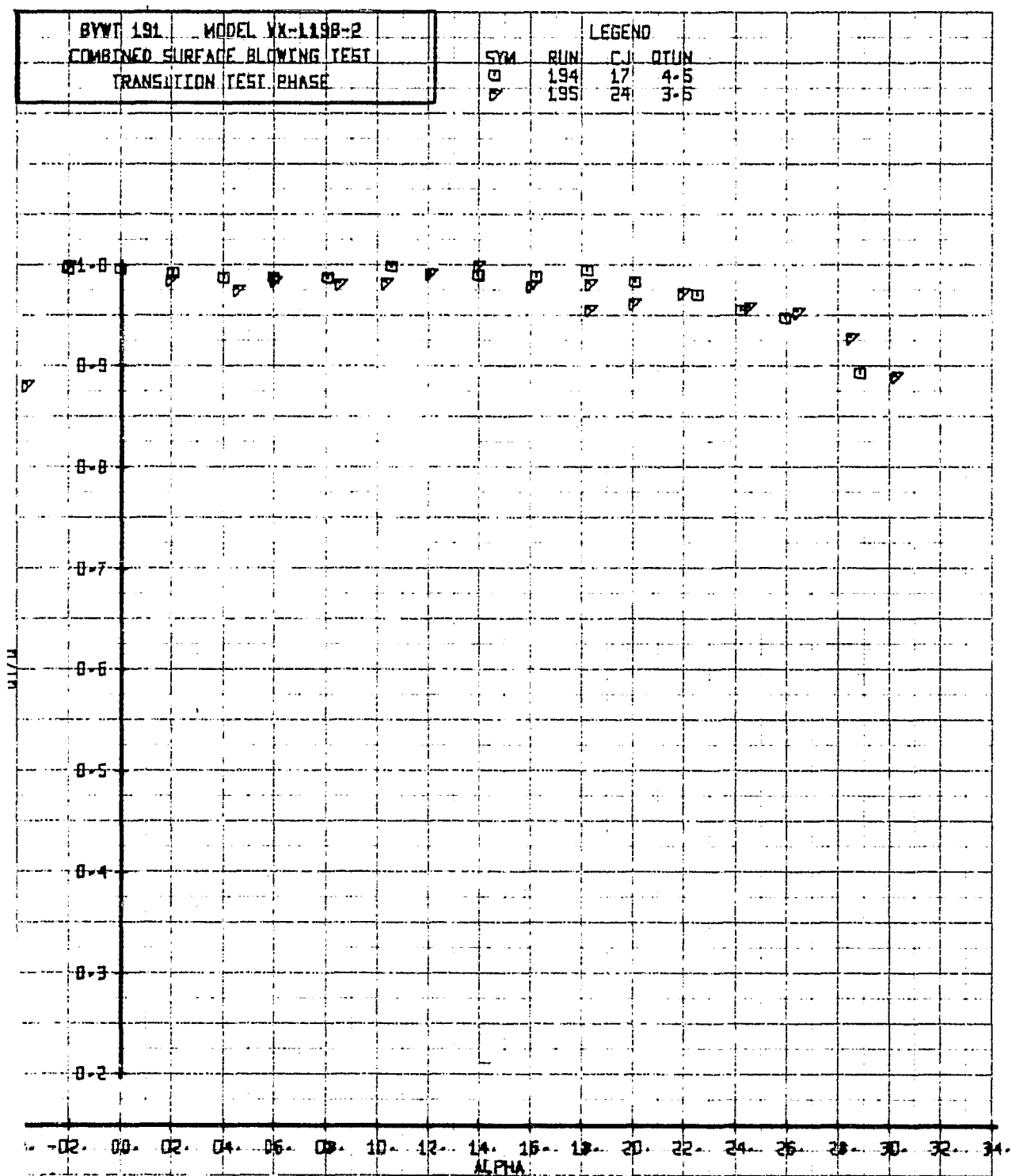


Figure 7.3-31. Retracted-Wing Downwash Characteristics with $\delta_f = 100^\circ/45^\circ$

b. $qt/q - \alpha$

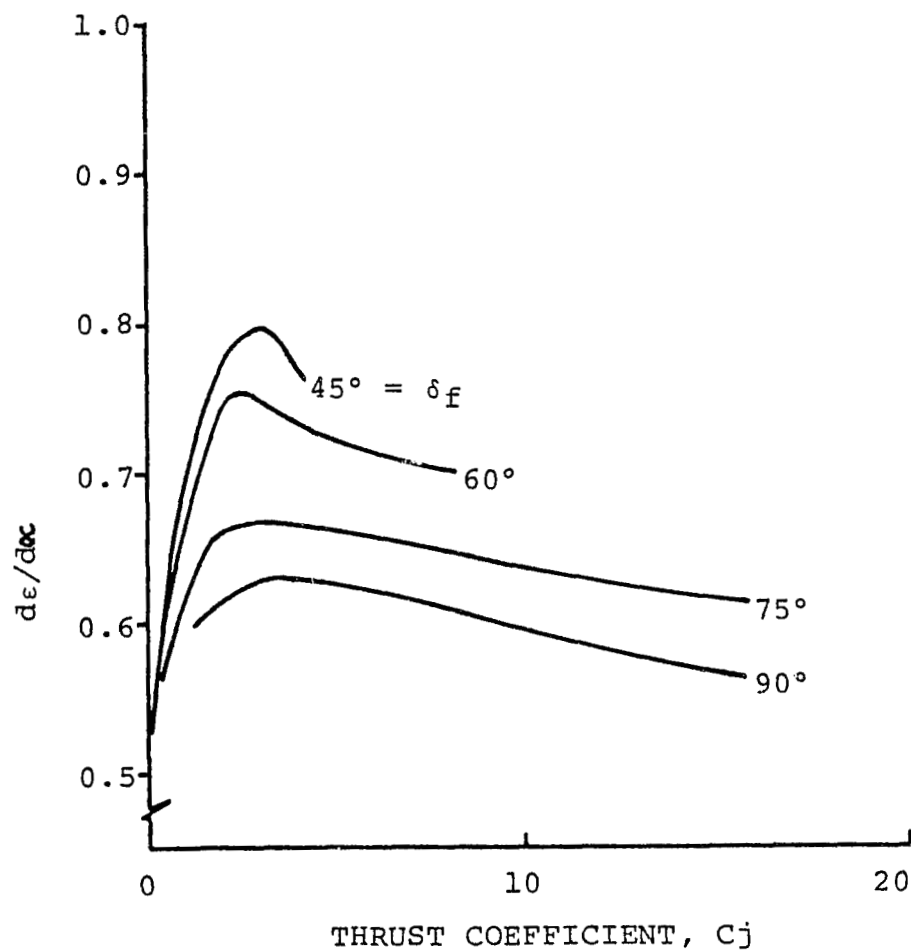
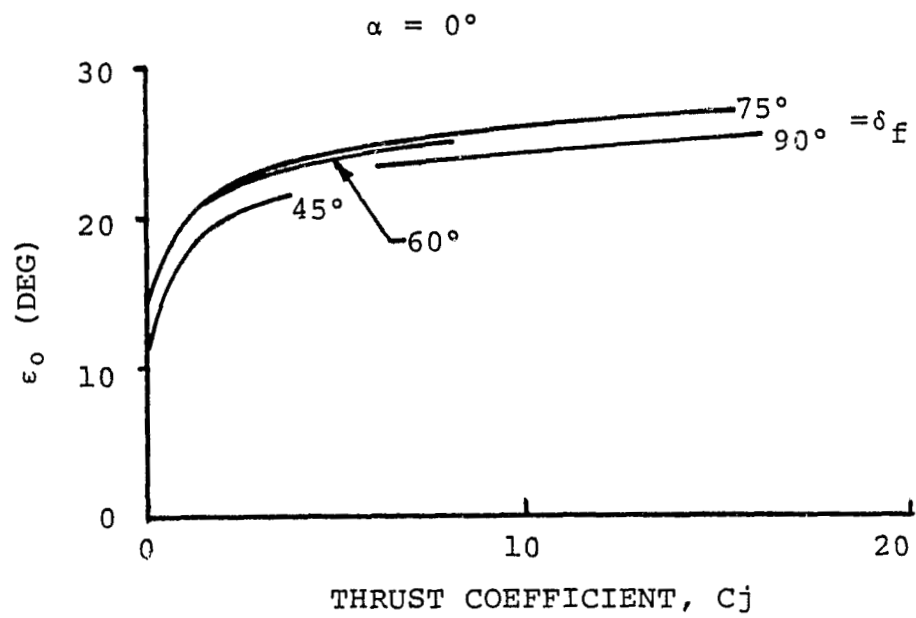


Figure 7.3-32. Downwash Summary, Retracted Wing

8.0 INTERPRETATION OF DATA

8.1 Climb Performance

Figures 8.1-1 through 8.1-3 show the steady climb performance for an airplane using the CSB lift/propulsion data from this test. The wing loading of the reference airplane was assumed to be 100 pounds per square foot. Each plot, representing a given flap deflection, has the data points from the constant-thrust-coefficient, α -sweep runs. Superimposed on this data are curves representing limiting angle of attack, constant wing attitude (reference to horizon), constant flight-path angle, and constant power. The curves shown are for the retracted wing.

8.1.1 Maximum angle-of-attack limit. — The lower solid line on each figure represents a maximum limit for angle of attack. These curves consist of two parts:

- At low thrust coefficient, C_j , the limit line corresponds to the maximum-lift coefficient. At these low C_j 's, the wing-lift curve exhibits a sharp stall break. This is shown on Figure 8.1-4.
- At higher values of C_j , the lift curve no longer breaks sharply at CL_{max} . There is a gradual, continuous rounding of the lift curve with maximum CL occurring at the condition where $\alpha + \delta f \approx 90$ degrees. In this range of thrust coefficient, the limit line corresponds to minimum flight-path speed (maximum resultant-force coefficient).

8.1.2 Angle-of-attack limit with margin. — The upper solid line on Figures 8.1.1 through 8.1.3, paralleling the maximum angle-of-attack limit, represents an α limit including a gust and stall margin. The gust margin used corresponds to a 20-foot/second gust normal to the wing and results in the step increase in α shown in Figure 8.1—4. The angle-of-attack limit with gust margin is offset from the maximum limit line by an amount such that if a gust occurred, the angle of attack would not exceed the maximum limit line. At low thrust coefficients, the margin is further increased so that with power off, the flight-path speed is always greater than $1.2 V_g$. In view of the exploratory nature of this test, these margins are considered adequate for analysis of the data in terms of descent capability.

8.1.3 Flight-path angle. — The long dash lines on these figures represent constant values of flight-path angles, γ . It should be noted that the flight-path angles can also be interpreted as steady values of deceleration for level flight from the relationship:

$$\left(\frac{\dot{v}}{g} \right)_{\text{level flight}} = (\tan \gamma)_{\text{steady climb}}$$

For example, an airplane with the capability to descend at $\gamma = -10$ degrees would also be capable of a level-flight deceleration of 0.176 g.

8.1.4 Wing attitude. — The short-dash curves represent constant wing attitude (θ_w) relative to the horizon. Thus it can be determined from Figure 8.1-1 that, with $\delta_f = 45$ degrees, level flight for the condition of level wing ($\theta_w = 0$) occurs at a speed of 90 knots.

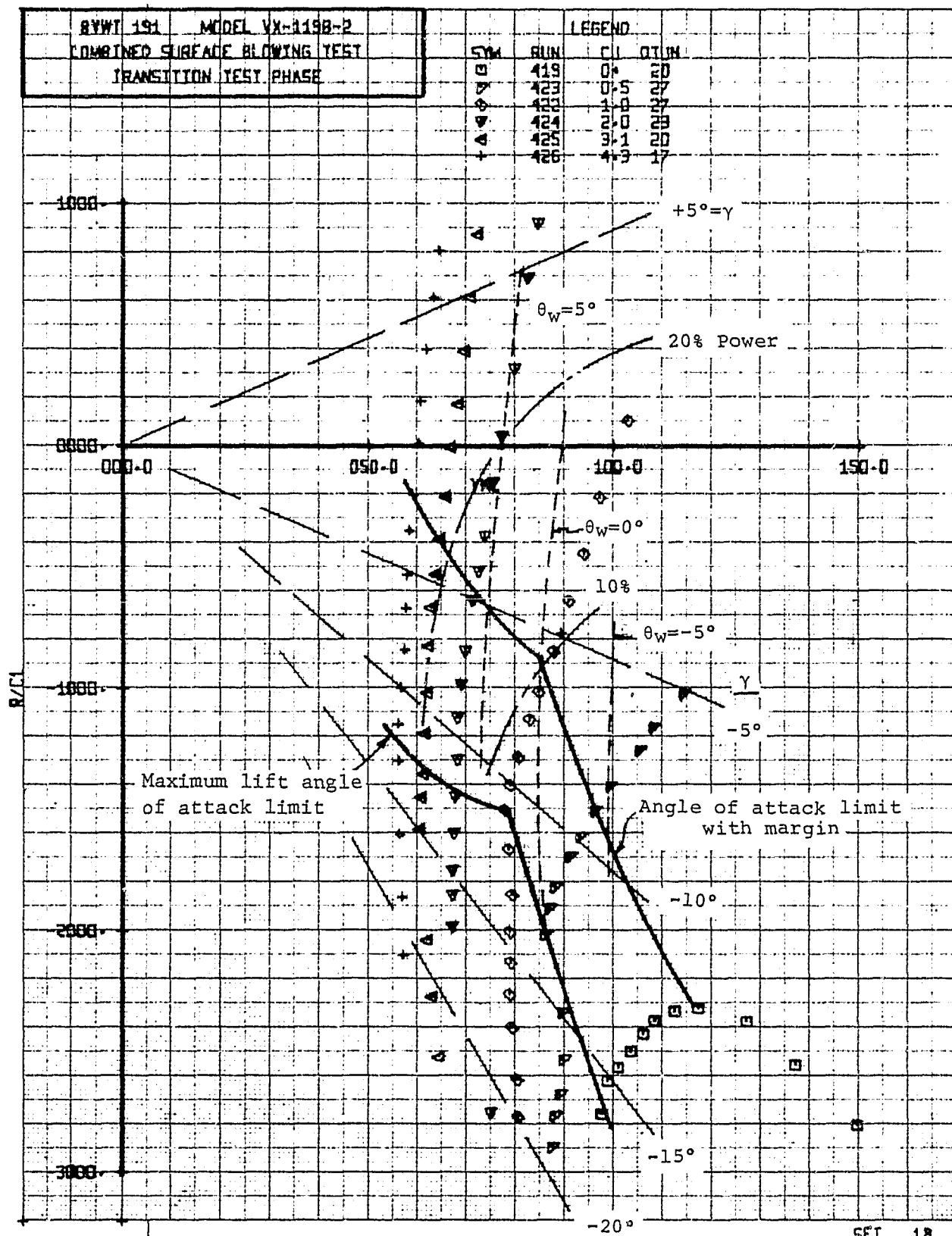
8.1.5 Constant power. — The dot-dash curves represent constant levels of power, as a fraction of hover power (equivalent to a thrust/weight ratio in hovering flight of 1.15).

8.1.6 Descent summary. — Figure 8.1-5 presents a summary of the descent performance obtained from Figures 8.1-1 through 8.1-3. Excellent descent capability exists for this stage of conceptual development, with steady descent rates in excess of 1,000 feet per minute.

8.2 Thrust Required

Figure 8.2-1 presents the schedule of flap deflection and power required for steady level flight at transition airspeeds for an airplane with a wing loading of 100 pounds per square foot. The net thrust required, as derived from the wind-tunnel data, is shown in Figure 8.2-2. Also shown in Figure 8.2-2 is a theoretical minimum for the thrust required, assuming optimum lift coefficient in combination with vectored thrust. The span-loading efficiency factor, $e = 0.79$, is a typical value for a wing with aspect ratio of 5.7. The curves shown fully demonstrate the benefits of the large levels of induced lift for the CSB lift/propulsion system.

Figure 8.2-3 shows the increase in lift/weight at low forward speeds provided by the jet-induced lift. The example used for this figure was a thrust-to-weight ratio of 0.5 and a wing loading (w/s) of 4788 n/m^2 (100 psf). Lift/weight = 1.0 (liftoff) is achieved at 42 m/sec (81 knots) in the absence of induced lift but is reduced to 28 m/sec (54 knots) when the induced lift is added. An auxiliary scale shows the ground-roll distance based on the simplifying assumption of ignoring the ground friction and the aerodynamic drag. Distances to liftoff are 686 meters (2,250 feet) without induced lift and 305 meters (1,000 feet) with induced lift.



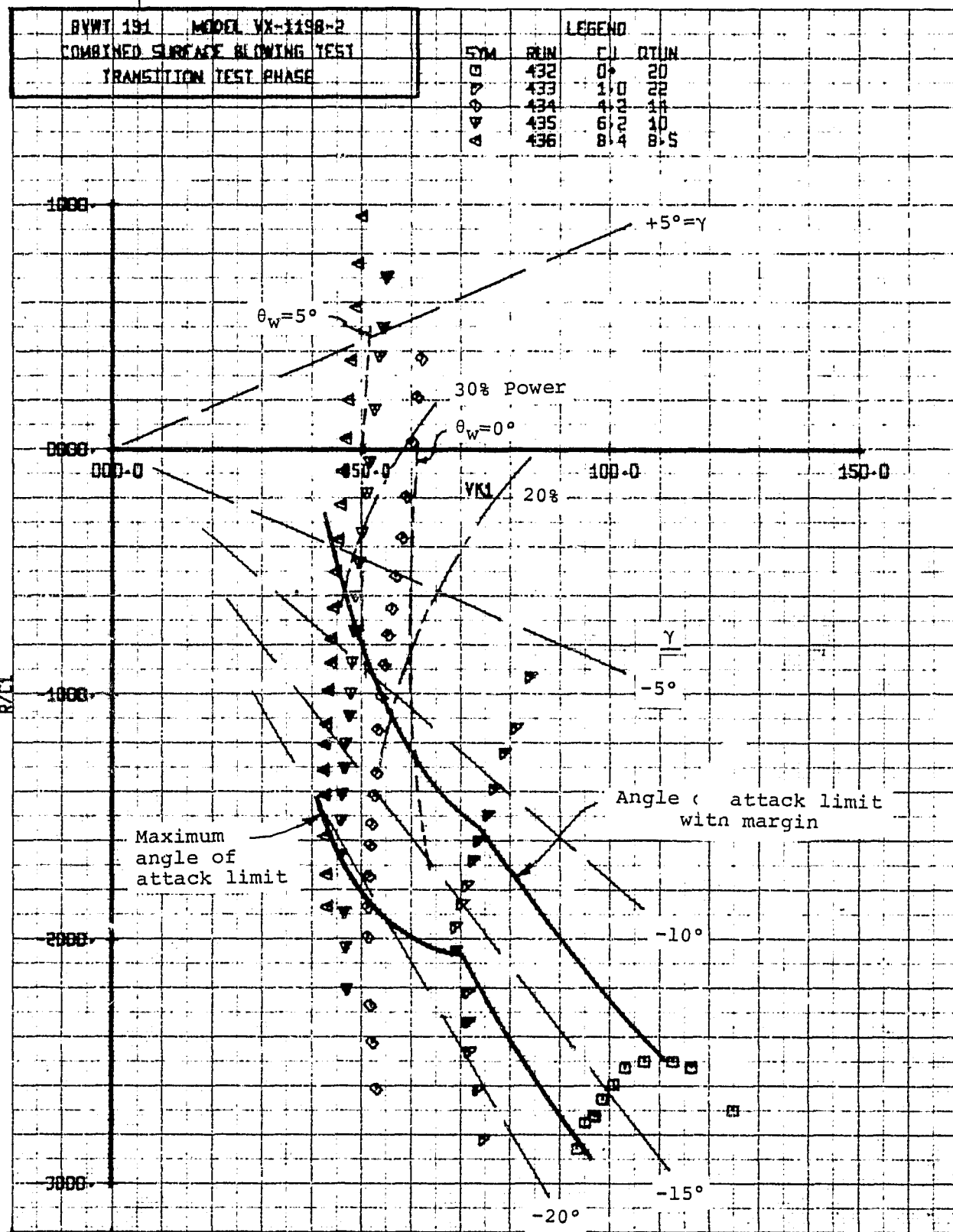
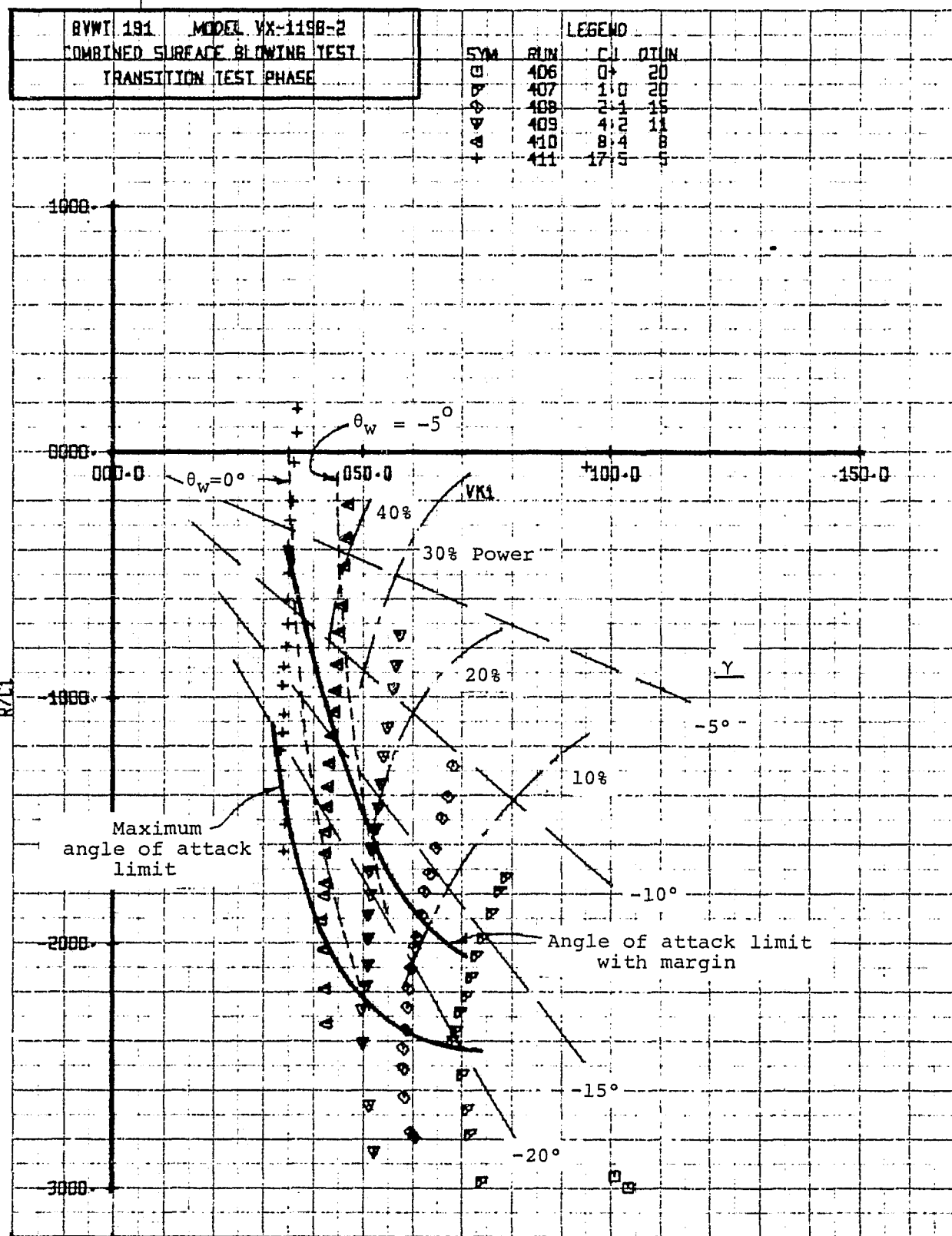


Figure 8.1-2. Retracted-Wing Rate of Climb, $\delta_f = 60^\circ$



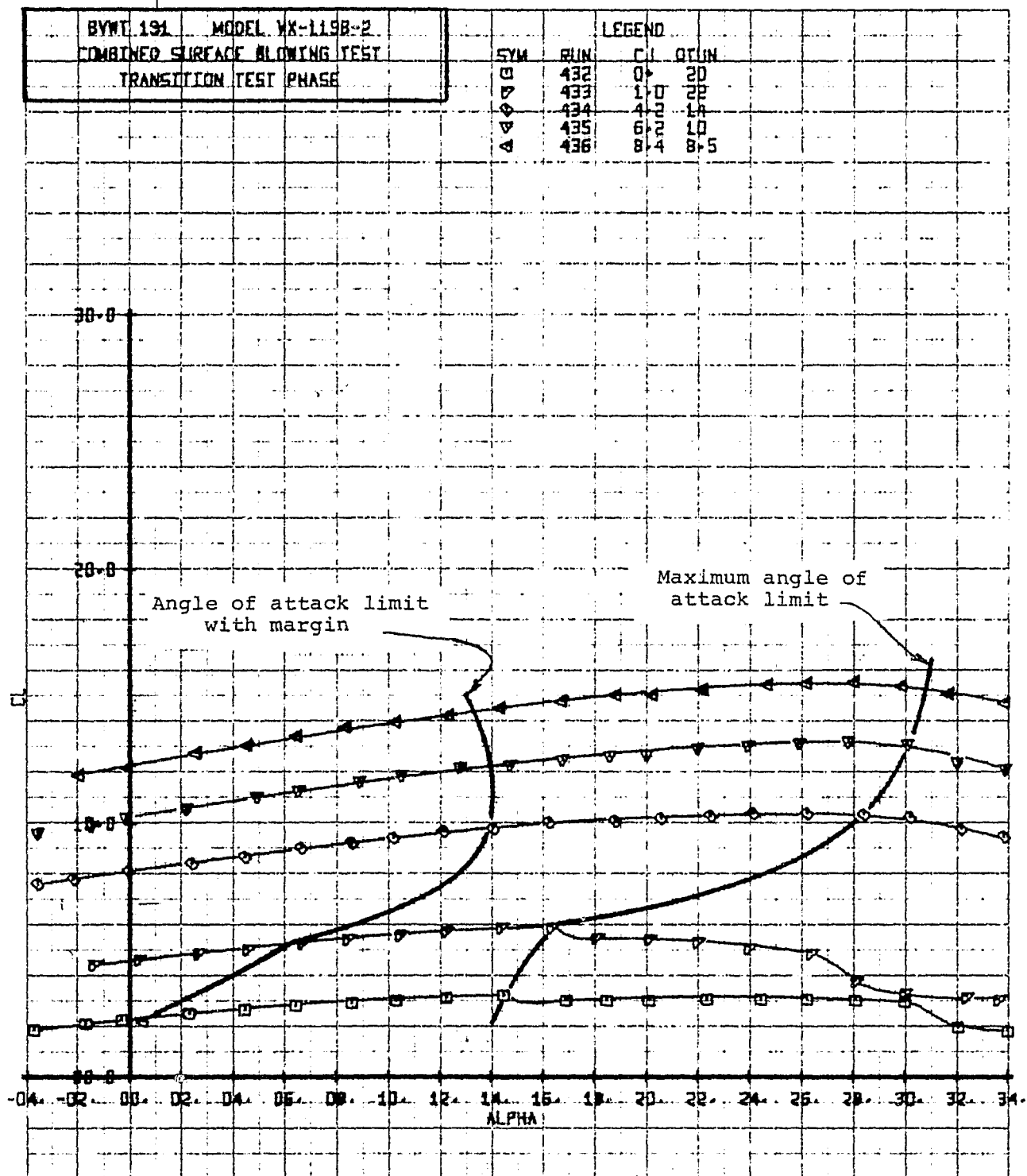


Figure 8.1-4. Lift Coefficient for Retracted Wing at $\delta_f = 60^\circ$
Showing Limiting Angle-of-Attack Lines

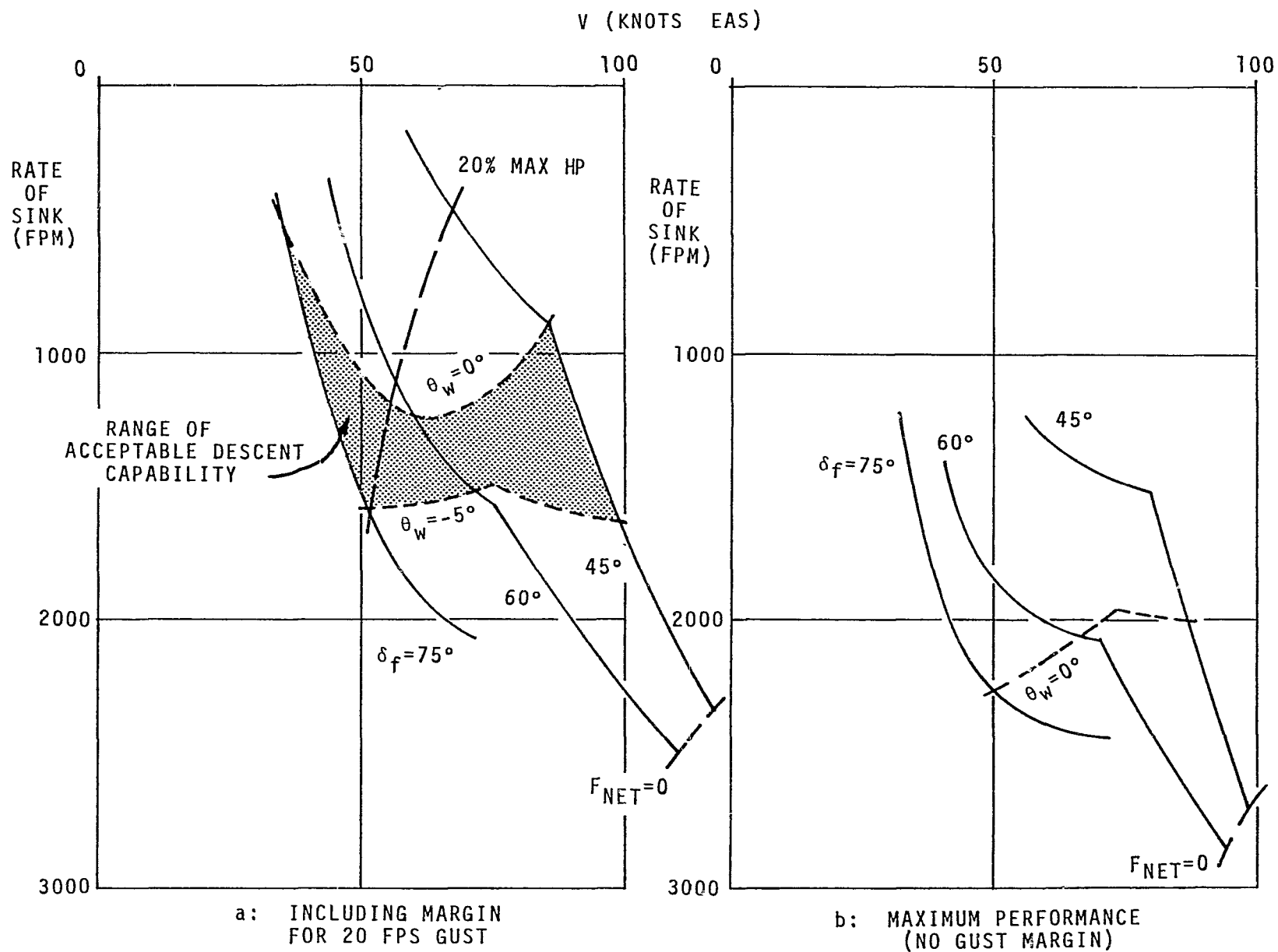


Figure 8.1-5. Retracted-Wing Descent-Performance Summary

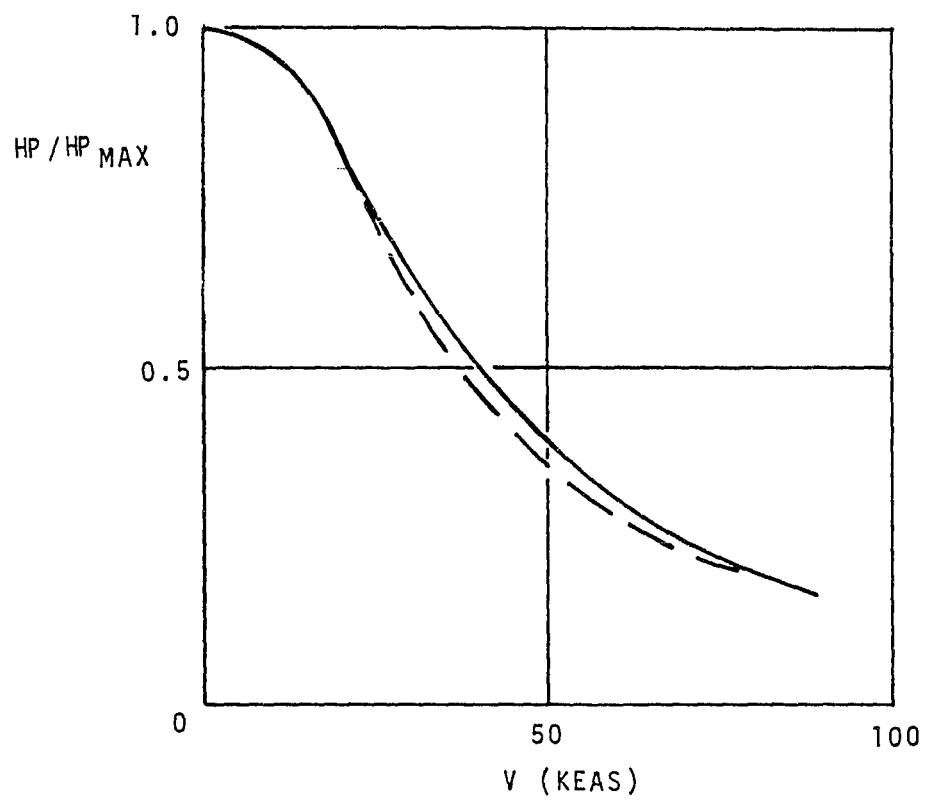
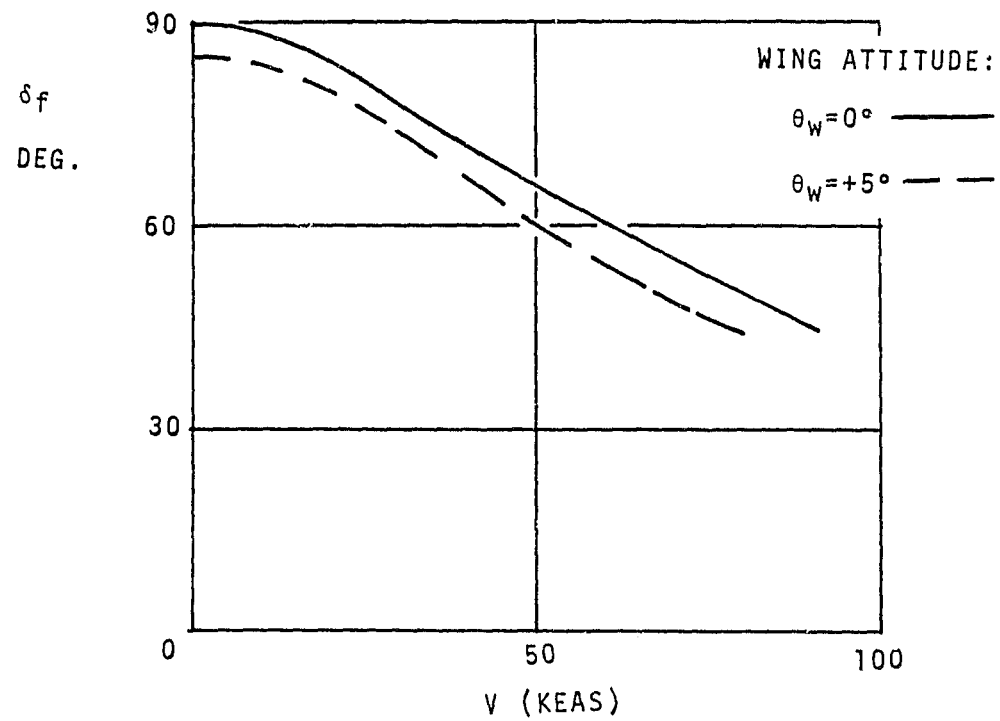


Figure 8.2-1. Flap and Power Schedule for Steady Level Flight

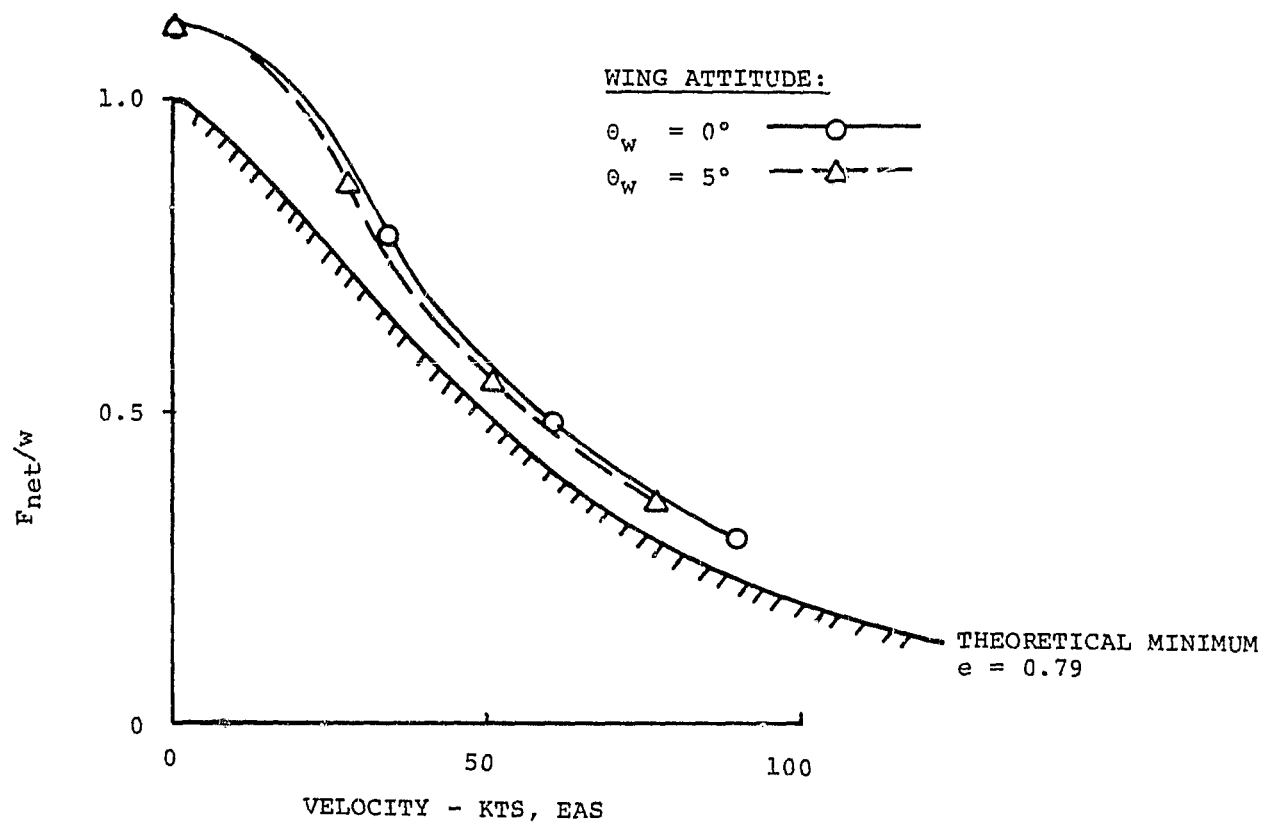


Figure 8.2-2. Thrust Required for Steady Level Flight

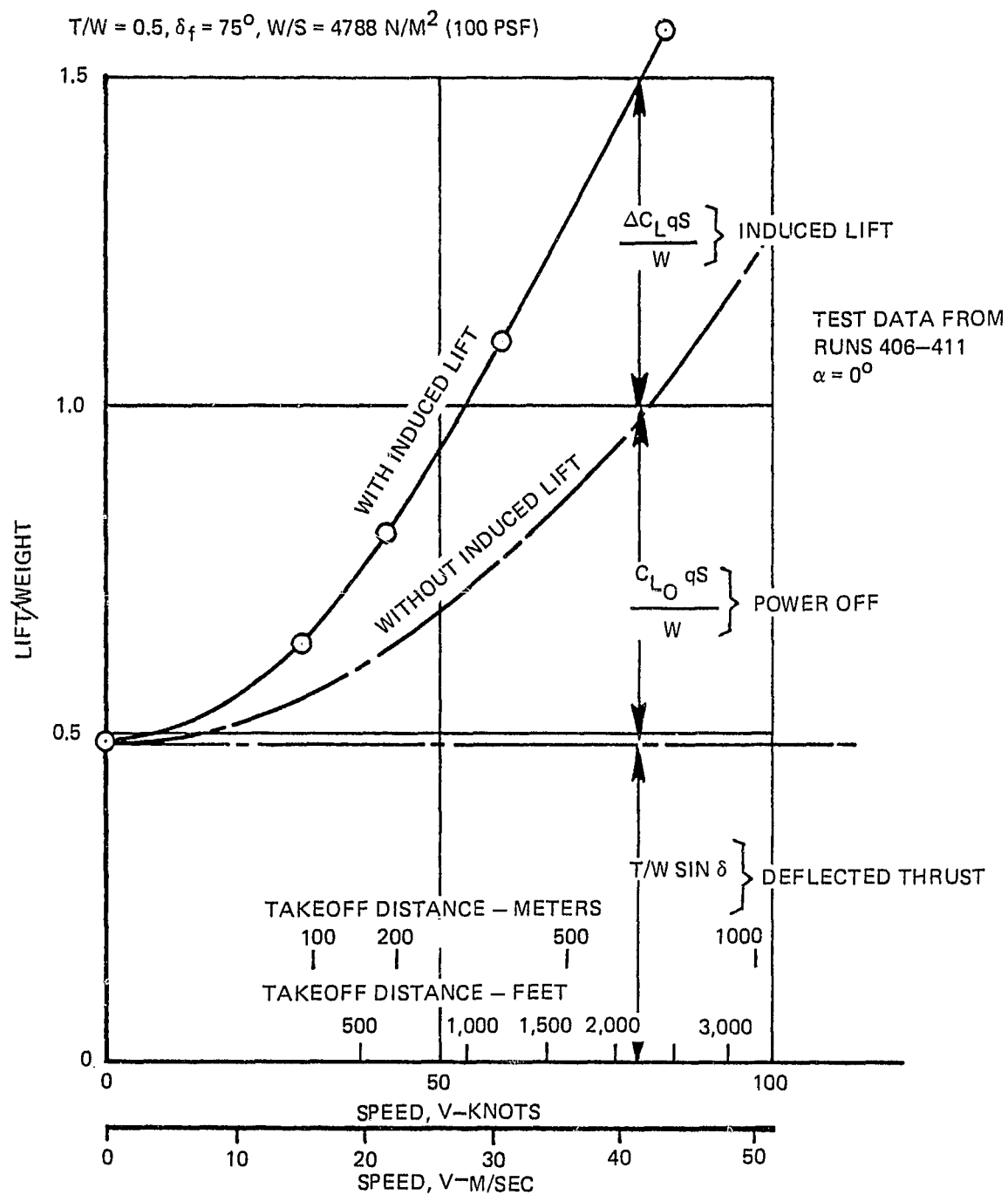


Figure 8.2-3. Increased STOL Performance Due to Jet-Induced Lift

9.0 CONCLUSIONS

9.1 Static Performance

- Static-performance levels were found to decrease with increases in pressure ratio above a pressure ratio of approximately 1.2.
- Static-performance levels of 89.6-percent thrust recovery combined with 87.1 degrees of thrust-vector angle were achieved at a pressure ratio of 1.2 with a flap deflection of 89 degrees. These levels of performance confirm the findings of the earlier NASA research.
- It was verified that larger slots are required for the blown flap than are normally associated with an unblown, slotted-flap system.
- Thrust recovery was nearly independent of flap deflection over the range of deflections from 45 to 105 degrees. The implication is that certain pressure losses develop due to brackets or slots when the flap is deployed and that additional losses do not occur due to increasing the deflection angle. An additional positive result from this finding is that thrust deflection beyond 90 degrees, required for control and hovering in a tailwind, does not cause significant additional thrust losses.
- The losses that occurred (approximately 10 percent of thrust) are most likely attributable to the slots or the brackets. The data indicates that the most likely slot loss is for the first slot, where a significant change in flow direction must occur for the flow which passes through that slot and where the presence of a separation bubble was identified.

9.2 Noise Measurements

- A data base of noise measurements was developed for comparison with noise data on other V/STOL concepts.
- The data obtained in this test indicates that, for upper-surface blowing, the acoustical shielding of the wing provides significant noise reduction on the ground.
- At low thrust levels there is little difference between combined-surface blowing and lower-surface blowing, but as thrust increases the noise associated with lower-surface blowing increases more rapidly. This indicates the possibility of significant aerodynamic noise cancelling when blowing over both surfaces at high velocities.

9.3 Transition Performance

- Tuft studies on the extended wing showed separated flow over the inboard unblown wing panel. For the retracted wing, this region of separation was confined to a small wedge-shaped area between the nacelle and the body. More detailed attention must be paid to correcting this condition in future tests. Localized tailoring of wing camber or wing-body fillets should provide an appropriate solution. A positive result was that the unblown outer panel of the wing had fully attached flow to angles of attack in excess of 25 degrees.
- The induced lift is a function of the jet Mach number as well as the thrust coefficient. For jet Mach numbers in excess of approximately 0.5 there is a reduction in induced lift. The severity of the compressibility effect increases as flap deflection is increased.
- For low jet Mach numbers, the induced lift was 55 percent of the value for a fullspan jet-flapped wing, even though only 27-1/2 percent of the wingspan was immersed in the jet.
- The descent capability was determined to be in excess of 1,000 feet per minute for an example airplane with a wing loading of 100 psf. This is in excess of the capability determined from the earlier NASA research and is excellent performance in view of the exploratory nature of the test.
- The thrust required for level flight falls off rapidly as speed increases, approximating the theoretical minimum value for an optimum wing-thruster combination.
- The additional circulatory lift induced by the jet can potentially reduce STOL takeoff ground-roll distance by approximately 50 to 60 percent.

9.4 Overall

- The CSB concept would be most appropriate for a low-pressure-ratio design:
 - The static performance generally reduces as pressure ratio is increased.
 - Compressibility effects associated with high-pressure-ratio design reduces the induced lift obtained in transition flight.

REFERENCES

1. Newsom, William A., Jr.: Wind Tunnel Investigation of a Deflected-Slipstream Cruise-Fan V/STOL Aircraft Wing, NASA Technical Note TN D-4262, 1967.
2. McCormick, Barnes W., Jr.: Aerodynamics of V/STOL Flight, Academic Press, New York, London, 1967.
3. Maskell, E. C.; and Spence, D. A.: A Theory of the Jet Flap in Three Dimensions. Proceedings of the Royal Society of London, Philosophical Transactions, Series A, Volume 251, No. 1266, page 407, June 1959.